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# THE PRINCIPLES OF ELECTROTHERAPY

## AND THEIR PRACTICAL APPLICATION

W. J. TURRELL

OXFORD MEDICAL PUBLICATIONS

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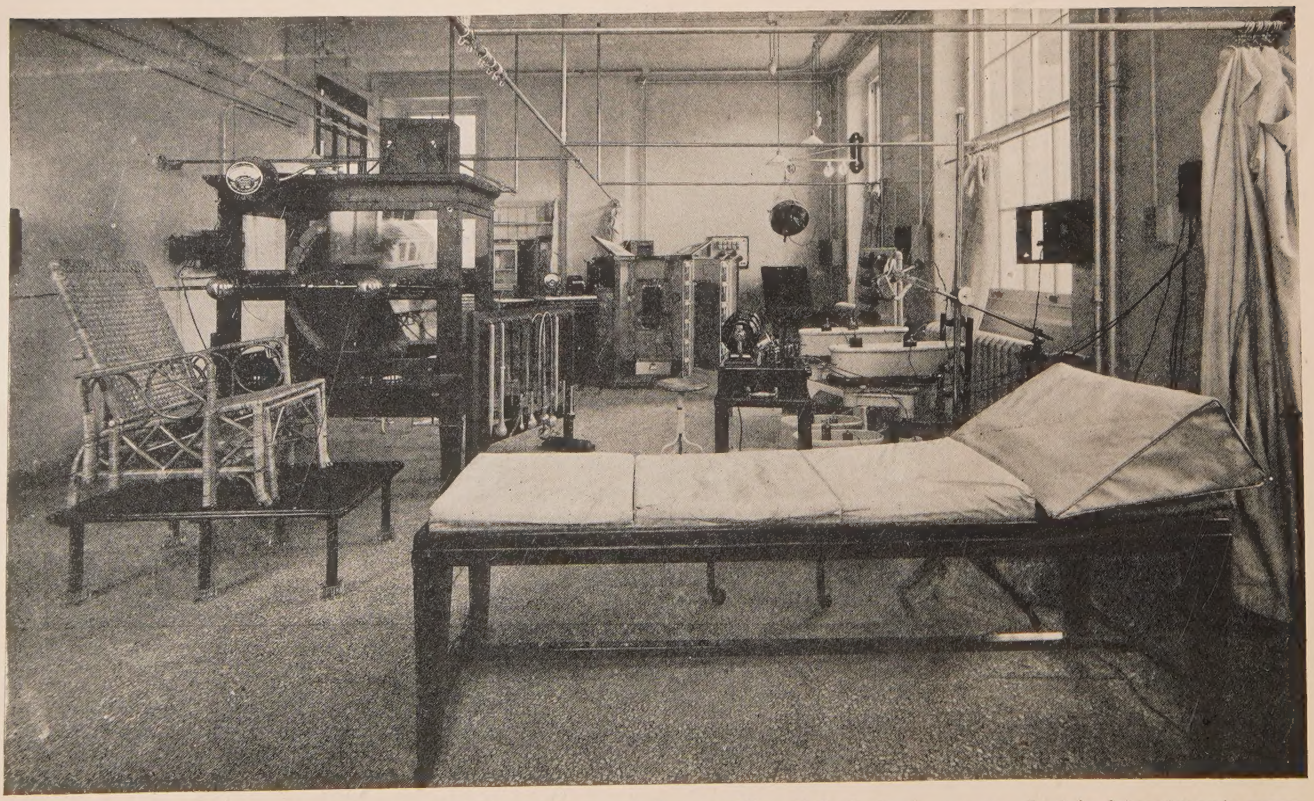
A PIONEER DEPARTMENT IN MODERN ELECTROTHERAPY. OPENED 1913.



The Electrical Department of the Radcliffe Infirmary and County Hospital, Oxford. 50,000 electrical treatments were administered in this department to wounded soldiers during the Great War.

OXFORD MEDICAL PUBLICATIONS

# THE PRINCIPLES OF ELECTROTHERAPY AND THEIR PRACTICAL APPLICATION

BY

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SECOND EDITION

*In knowledge, that man only is to be contemned and despised who is not in a state of transition.'*

MICHAEL FARADAY

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# PREFACE TO THE SECOND EDITION

THE whole of this book has been extensively revised, and many parts have been entirely re-written. Chapters have been added on the history of medical electricity, on the accidents liable to attend its administration, and on the practical details of its application.

In the first edition, when dealing with the constant current, more attention was paid to exposing the fallacy of ionic medication than to explaining the action of the constant current. In this edition the latter point has been more fully considered and the benefits obtained from the administration of the constant current are found to be attributable more to the local reflex stimulation of the nerve endings in the skin of the afferent nerves than, as was assumed in the first edition, to the deep heating effects produced by the ionic bombardment set up by the current in its passage through the tissues.

The heating effect of such a bombardment is undeniable, but its extent is probably insufficient to account entirely or even chiefly for the benefits obtained from the administration of the constant current.

The skin has for far too long been regarded by the medical profession as 'merely a thing of sores and pimples'; the various forms of physio-therapy clearly show that it is an organ of extreme importance in the regulation of many of the bodily functions. From the point of view of physio-therapy, the skin may be regarded as a relay station at which external stimuli are received and thence relayed by the path of the afferent nerves to the various nerve centres concerned with the regulation of the ductless glands and other organs of the body. The constant current is the most effective agent at our disposal for the local stimulation of these skin reflexes.

In the case of the high-frequency currents, the most important of the recent advances appears to be the increasing recognition of the fact that these currents do not

owe their therapeutic effects to their heating action alone, but also to the more fundamental action of the ionic oscillations and vibrations which precede and produce the heating effect.

If this view is accepted, it is clear that two types of H.F. apparatus are needed; the one yielding H.F. currents of tension, for which purpose the older type of H.F. machine is the more suitable; the other yielding H.F. currents of quantity, for use when the heating effect is mainly required, and for this purpose the triode valve machines are more effective.

Special attention is drawn to the remarkably good results that have followed the application of diathermy in the treatment of pneumonia, and Dr. Eaton Stewart's work in America, in initiating and perfecting the technique of this treatment, is extensively referred to.

The chapter on ultra-violet radiation has been considerably extended, and a new method for the administration of the correct dose is described.

Radiotherapy is only dealt with to the extent to which it can be readily and effectively applied by the electrotherapist: the importance of its inclusion within the scope of his work within these limits is strongly emphasized. Deep or intensive radiotherapy is a speciality of its own.

In the chapter on electrical accidents, the author would call special attention to the important work of Professor Jellinek on death from high voltage electricity. Professor Jellinek has established the fact that death from high voltage electricity is in the first instance only apparent death, and, if artificial respiration is immediately and efficiently applied, life will be restored in the majority of cases.

In view of the frequent deaths reported from high voltage electrical shock, and of the increasing frequency of such deaths with the rapidly extending application of electricity to industry, it is difficult to exaggerate the great importance of Professor Jellinek's work and the need for its more general recognition and practical application.

The explanation of the manner in which this apparent death is brought about is to be found in the hypothesis that is so much stressed in this book, namely, that the underlying factor governing the physiological action of current electricity is the relatively high velocity of the hydrogen and hydroxyl ions and the consequent concentration of these ions at the make, and break, or sudden variation in the strength of the electrical current: for, in the case of apparent death from electrical shock, it is the hydrogen ion concentration at make and the hydroxyl concentration at break that stimulate the inhibitory action of the vagus and so induce apparent death.

In this edition I must again express my great indebtedness to the writings of French and American electrotherapists: the frequent references in this book to the French journals, the *Archives d'Electricité Médicale* and the *Journal de Radiologie et Electrologie*, afford a striking proof of the great value of these periodicals in aiding the advance of modern electrotherapy.

In conclusion I should like to express my appreciative thanks to my colleagues, Dr. David Barnes, Assistant Electrotherapeutic Physician to the Radcliffe Infirmary, and to Mr. D. A. Abernethy, Assistant Surgeon to the Radcliffe Infirmary, for their valuable assistance in the preparation of this edition.

W. J. T.

*January* 1929

# PREFACE TO THE FIRST EDITION

THIS book is the outcome of an attempt to explain the therapeutic action of electricity upon rational grounds and upon physiological principles.

In Part I current electricity is discussed. The therapeutic action of static electricity is here considered, because it is mainly the currents derived from the static machine, and not the static charge itself, which possess therapeutic action. The static machine serves to generate a static charge, which, when sufficient voltage has been attained, discharges as a current of very low intensity, but of very high potential, and so affords methods of therapy unattainable by other means.

The necessity of clearly distinguishing between the polar and inter-polar action of the constant current is pointed out. The action of interrupted currents of low frequency is shown to be due to the relatively high velocity of the hydrogen ion compared to the velocities of the other ions in the tissues.

The steps by which D'Arsonval was led to the discovery of high-frequency currents are described, with extracts from D'Arsonval's original paper. The action both of high-frequency currents of tension and of quantity are fully discussed.

The second part of this book deals with the fascinating and difficult task of explaining the therapeutic action of radiant energy. Tracing this method of treatment from its general principles we are led step by step to formulate a new hypothesis, or, perhaps, to develop an existing theory of the therapeutic action of the radiation from an X-ray tube or radium. We first of all note the fundamental identity of the mode of action of ultra-violet radiation with that of the radiation from X-rays and radium. We realize that radiation, like light, only acts when it is absorbed, and we next find that Kohler has shown that the nuclei of the cells in the gill plate of the salamander

are 'particularly opaque to light of the wave length of the ultra-violet' (Bayliss). Tracing this subject farther we learn from Dr. Regaud that it is the chromatin of the nuclei, at the time of their division, which is the most radio-sensitive component of the human tissues, and consequently is the first to be destroyed by the radiation of X-rays. We are, then, met with the difficulty that the immediate destruction of the cells does not account for the latent period which precedes the characteristic reactions of both ultra-violet radiation and X-rays. To account for this latent period, we suggest the setting free of some toxin resulting from the splitting up of the chromatin. Passing on later to discuss the very important question of the action of X-rays on the blood, we find that the presence of such a destructive toxin or ferment, a leucolysin, has been clearly demonstrated by Curshmann and Gaupp, as occurring after the exposure of a leukaemic patient to X-rays. We are thus enabled not only to complete the evidence in support of our theory, but also to suggest an explanation of the recognized diminution in the efficiency of repeated radiation by X-rays in the treatment of leukaemia, on the possible and rational ground that, as the outcome of the action of the toxin, antibodies are developed which render the white corpuscles less radio-sensitive.

The recent work of the Erlangen gynaecologists, Drs. Seitz and Wintz, appears likely to revolutionize to a very large extent our views on radiotherapy. At first sight we are apt, impressed by the great increase in the power of their apparatus and the prolonged exposure which they administer, to lose sight of the careful and far-reaching experiments upon which their methods are based.

It is, however, from the latter, and especially from their systematic tabulation of the varying lethal doses required to destroy different types of cells that the most lasting and valuable results are likely to spring. A single instance will suffice to illustrate this point: if 40 per cent. of the unit skin dose, as Drs. Seitz and Wintz state, has the effect of stimulating rather than destroying cancer cells, then the

present practice of employing prophylactic radiation, before operation, and also post-operative radiation, should be immediately discontinued. For the doses generally given in this country for these purposes do not usually exceed this 40 per cent., and consequently their application is far more likely to prove harmful than beneficial: moreover, the necessary lethal dose required to destroy cancer cells is far too drastic and provokes too grave constitutional disturbances to be used for prophylactic purposes.

It is not possible within the limits of this book to give more than a broad outline of the work of the Erlangen technique, and it is far too early to pronounce definitely upon its merits; but as it is certain that this method of treatment will exercise a most powerful influence on the future of radiotherapy, an attempt has been made to deal briefly with its essential points.

The third part is concerned with electro-diagnosis. The chief portion, dealing with the electrical diagnosis of peripheral nerve lesions, has already appeared in the *American Journal of Electrotherapeutics*. A chapter on the electro-diagnosis of certain diseases has been added.

The fourth part explains the action of electrotherapy in some of the diseased conditions for which it is applied, and indications are given of the type of case suitable for electrical treatment. To this part some practical hints on treatment are added.

In the compilation of this book I have drawn very largely upon the writings of French electrotherapists—in no other way would it be possible to deal adequately with this subject. No student of the history of electrotherapy can fail to recognize the fact that this form of treatment was first placed upon a scientific basis as the result of the work of French scientists. Imbued, perhaps, with the pride of antiquity, we trace the pedigree of this speciality back to the writings of the ancient Greeks: yet, nevertheless, every electrotherapist, whatever his nationality may be, is proud to claim as the Founder and the Father of Modern Electrotherapy that great scientist, Duchenne, of

Boulogne, whom a French speaker so well described as 'the man who has played a preponderating part in the researches and discoveries upon which the edifice of neuropathology has been erected'. These researches were based upon, and these discoveries resulted from—as Duchenne himself states—'a method of electrization, which surpassed his expectation in yielding scientific and practical results of the highest importance'.

I am especially indebted to the writings of Professor Bergonié, Drs. Miramond Laroquette, Nogier, Bordier, Béclère, Larat, Regaud, Max Roques, and MM. David and Desplats.

Due acknowledgement must also be made of the assistance in reference to the static machine which I have received from the writings of Dr. Benham Snow, of New York, who has done so much to develop the use of this instrument; and in connexion with the same subject I should like to record my indebtedness to Dr. Howard Humphris, to whose kindness I owed my first introduction to this useful machine, and also many valuable hints in regard to the methods of employing the currents derived from it. In dealing with radiant energy I have been greatly assisted by Professor Merton's kind advice and helpful criticism. Like other radiotherapists in this country I was indebted for my earliest information of the Wintz method to Dr. Reginald Morton, whose paper, published in the *Proceedings of the Royal Society of Medicine,* I have so largely drawn upon when dealing with that intensive method of radiotherapy. I have also, in discussing this important subject, availed myself of some extracts from the comprehensive book of Drs. Seitz and Wintz.

To Dr. E. D. Adrian, of Cambridge, whose experimental work has done so much to elucidate the principles upon which electro-diagnosis is based, I owe my thanks for his kind permission to utilize the illuminating diagrams of a case of recovering facial paralysis. Finally, I must not omit to acknowledge the great assistance I have derived from repeated and careful perusal of that mine of physio-

logical information, Professor Bayliss's *Principles of General Physiology*.

In conclusion, I would venture to express the sincere hope that this small book may in some slight degree help to harness to the service of the healing art the most powerful, the most easily regulated, and the most fundamental force in nature.

W. J. T.

1922.

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# PART I

# HISTORICAL

## CHAPTER I

## THE HISTORY OF ELECTROTHERAPY

IT is probable that, even in prehistoric times, the physiological effects of electricity were unpleasantly experienced by unwary bathers and fishermen in the Mediterranean seas from contact with the electric ray, or torpedo fish, three or four varieties of which are met with in those waters.

Aristotle (341 B.C.) states that these fish have the power of benumbing men, and Pliny (A.D. 79) relates that 'this fish, if touched by a rod or spear, even at a distance, paralyses the strongest muscles, and binds and arrests the feet however swift' (1); he also prophetically hints that considerable therapeutic benefit may be reasonably expected from creatures endowed with such natural powers.

Anthero, a freedman in the time of the Emperor Tiberius, is stated by Scribonius Largus (A.D. 50) (2) to have been cured of an attack of gout by placing his feet on the back of a torpedo fish.

Dioscorides (3) recommends shocks from the torpedo fish as a cure for obstinate headaches. A similar form of treatment is advocated both by Galen (4) (A.D. 144) and by Paulus Aegineta (5).

The electric ray, or torpedo fish, belongs to the elasmobranch family; its electric organ consists of about 800 to 1,000 cells connected with large bundles of nerves. It grows to a width of three or four feet, and, when fully grown, is said to be capable of giving a shock sufficiently powerful temporarily to paralyse a limb.

The dorsal surface of the fish is positive and its under surface is negative.

According to the writer on Animal Electricity in Todd's

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*Cyclopaedia of Anatomy and Physiology*, 1839, the torpedo fish was still used by the Arabians as a therapeutic agent at the beginning of the nineteenth century. The method of administering the shocks is thus described: 'The patient is placed on a table, and the fish applied to all the members of the body in succession, so that each should receive at least one shock. The treatment causes rather severe suffering, but enjoys the reputation of being febrifuge.'

Muschenbroek, about 1750, was the first to infer that these shocks were electrical in origin; he drew this inference from their resemblance to the shocks received from a Leyden jar.

The gymnotus, or electric eel, is another fish capable of giving powerful electrical shocks.

Since the electrical nature of these shocks was not recognized until about 1750, electricity may be said to have been first discovered when Thales of Miletus (600 B.C.), one of the Wise Men of Greece, found that amber, on being rubbed, attracted light bodies. This phenomenon induced Thales to believe that amber was endowed with life, and that it derived nourishment from the objects it attracted.

From the Greek name for amber (ἤλεκτρον) the term electricity has been derived.

About 300 B.C. Theophrastus, in his book on 'Precious Stones' (6) states that this property of amber is also possessed by lyncurium (tourmalin).

For nearly two thousand years no further advance was made in electrical knowledge. In 1600 there appeared a book entitled *De Magnete, Magneticisque Corporibus, &c.*, by the President of the College of Physicians for that year, Dr. William Gilbert (1540–1603), a native of Colchester and physician to Queen Elizabeth.

Gilbert found that there were many bodies, such as precious stones, sulphur, glass, &c., which when rubbed attracted light bodies. He defined electrics as: 'Electrica; quae attrahunt eadem ratione ut electrum'.

Gilbert noticed that the electrics were much more

readily electrified when the atmosphere was dry than when it was wet; when the wind was in the north or east than when it was in the south. He also found that electrification was facilitated by warming the bodies to be excited.

To the inventive genius of Otto von Guericke (1602–1686), Burgomaster of Magdeburg, the discoverer of the air pump, we owe the first frictional machine for the production of electricity. Guericke constructed his machine by filling a glass globe with sulphur, then, not being aware that the glass globe would function as well as the sulphur, he broke the glass and mounted the sphere of sulphur on a wooden frame. With this machine, by holding his hand in contact with the rapidly rotated sphere, he was able to produce sufficient electricity to enable him both to hear and see the spark.

Guericke was the first to discover that bodies bearing similar electrical charges repelled one another.

Hawksbee, who wrote about 1709, substituted a glass globe for the sulphur sphere, and performed some important experiments in connexion with electrical attraction and repulsion.

About 1742, Winkler, a professor of languages at Leipsic, introduced a cushion or rubber, in place of the hand which had previously been used to excite the machines. This improvement shortly afterwards led to the introduction of machines with multiple glass globes. According to Priestley, from whose book, *History of Electricity*, most of our information in regard to the development of electricity at this period is derived, 'such a prodigious quantity of electricity could they excite from these globes, whirled by a large wheel and rubbed with woollen cloth . . . that, if we may credit their own accounts, the blood would be drawn from the finger by an electric spark, the skin would burst, and a wound appear as if made by caustic'.

In 1745 electrical research was facilitated by the discovery of the Leyden jar. This advance was due, not to Muschenbroek, as Wesley and others erroneously state, but to von Kleist, Dean of the Cathedral at Camin, who on

November 4, 1745 sent the following account of his discovery to Dr. Lieberkühn, at Berlin: 'When a nail or a piece of thin brass wire &c. is put in a small apothecary's phial and electrified, remarkable effects follow; but the phial must be very dry and warm'. This does not seem a very intelligible description of the Leyden jar, but R. Lovett, in his *Philosophical Essays*, 1766, describes a method of construction which differs little, if at all, from that employed at the present day: 'But the most commodious way is to line the inside of the phial with gold leaf, &c., and to coat it with tin foil, thin lead, or the like, and to fasten some tinsel fringe or fine wires to the lower end of the cork wire within the phial, so as to reach the gold lining, by which means the electrical fire is conveyed to it from the revolving rubbed glass'.

Von Kleist, in his letter to Lieberkühn, after describing his jar, gives an account of the powerful spark which he obtained by its means. His arms and shoulders were benumbed by its action, and he expresses the opinion that Mr. Boze would not have desired a second kiss from the jar. Priestley, however, to whom Mr. Boze was known as a charlatan, differs from this opinion, and states, presumably in a sarcastic vein, that the sentiments of the magnanimous Mr. Boze were far different, 'who with a truly philosophical heroism, worthy of the renowned Empedocles, said he wished he might die by the electric shock, that the memoir of his death might furnish an article for the memoirs of the French Academy of Science'.

Muschenbroek, in a letter to Réaumur, states that it took him two days to recover from the shock, and that he would not repeat the experiment for the kingdom of France. Priestley quotes many other instances of the terror inspired by shocks from the jar in Germany and France.

Among many other experiments made with the Leyden jar at this period, the Abbé Nollet tried how many patients he could shock at the same time. He first gave a simultaneous shock, in the presence of the King of France, to 180 of the royal guards. Afterwards, in the grounds of the

Grand Convent of Carthusians, at Paris, the whole community being lined up in a row 1,800 yards long, a shock was administered that elicited a simultaneous spring from them all.

About 1760 a glass-plate friction machine was independently introduced by Dr. Ingenhausz, of Vienna, and Mr. Ramsden, of the Haymarket, London. It consisted of a circular plate of glass excited by four rubbers. Priestley comments on this machine as being ingenious, but states that there was a difficulty in insulating the rubbers, and that the machine was more fragile than those with glass globes.

We have now arrived at a period of great activity in electrical research, and it is not surprising to find that medical men and others, furnished with an electrical machine of considerable power, and also provided with the Leyden jar, which was capable of greatly increasing the output from these machines, turned their attention to the curative effects of electricity. Before, however, electricity was applied to the treatment of disease, the Abbé Nollet had made several experiments in reference to its effects on animals.

At different periods the title of 'The Father of Electrotherapy' has been bestowed on several electrotherapists, notably upon the great Duchenne, of Boulogne. But this honour of paternity undoubtedly devolves most justly upon Christian Gottlieb Kratzenstein, who was the first to practise electrotherapy systematically and was the first to suffer for his enthusiastic advocacy of its efficiency. (7)

Kratzenstein was evidently a man of wide scientific attainments, for in the course of his career he acquired a knowledge of many cognate subjects to a degree that is unfortunately foreign to many modern specialists. He was born at Wernigerode, of which town his father was burgomaster, in 1723. He studied at Halle, and whilst there wrote, in the year 1745, the first book on electrotherapy, *Abhandlung von dem Nutzen der Electricität in der Arznei-*

*wissenschaft.* (8) He was successively professor of physics at Halle in 1747, professor of mechanics at St. Petersburg in 1749, dealing there also with astronomy and nautical problems, and professor of experimental physics at Copenhagen, 1753. At Copenhagen he was appointed by the King of Denmark to study the effects of electricity on disease. In addition to his other work, he delivered popular lectures, wrote to the lay press, and advertised for patients. It is therefore no matter for surprise that he was regarded by his fellow professors as 'a vulgar pushing fellow'. (7)

His method of electrical treatment was by means of a large revolving frictional glass globe, the patient being insulated on a wooden stool. He drew sparks from his patients, who experienced pain in consequence in their toes, probably on account of the insufficient insulation. The procedure was accompanied by a smell of sulphur. Kratzenstein claimed that the most minute parts of the organism were shaken by the electricity and that the sulphuric and salt particles were driven out from the body, hence the sulphuric smell. He further claimed that the circulation of the blood and the arterial tension were increased.

He argued that, as an excess of blood was the cause of most diseases, he obtained better results by driving the blood out of the affected tissues than by mere bleeding. After the treatment the patients were tired and sleepy, as though they had performed considerable work, hence electricity acted as a narcotic. Electricity was useful in paralysis as the nerves were shaken up by the current.

Kratzenstein's success is suggested by the reputation he acquired as a magician, a most unenviable reputation in the days in which he lived. As the result of this, it appears that 'no landlord could be found in Copenhagen to house a man whose experiments in electricity were sure to attract lightning and raise fires'.

Among other methods he adopted was that of centrifugalizing his patients in order to determine the flow of blood to the hands or feet as might be required. He, more-

over, recognized the danger of copper cooking vessels, and recommended their being coated with tin.

He was evidently a very resourceful and enterprising pioneer. Priestley states that the first account that he had 'met with of the application of electricity to medical purposes is that of Mr. C. Kratzenstein, professor of medicine at Halle, who in the year 1744, cured a woman of a contracted finger in a quarter of an hour'.

From this date electrotherapy owes its progress chiefly to French workers. This form of treatment appears to have appealed to the imagination of the French, and they approached the subject in a more scientific spirit than did the workers in other countries. About the year 1750 an official commission was held at the Hôtel Royal des Invalides, Paris, and experiments were performed before by Dr. Lassonne, physician to the King, Morand, surgeon to the hospital, and the Abbé Nollet. These experiments were not successful.

Jallabert, professor of philosophy in Geneva, had, in 1747 and 1748, obtained very similar results to those of Kratzenstein, and had proved particularly successful in the treatment of paralytics. Inspired by these reported successes, Sauvages, of the Montpellier Academy, attempted the cure of paralysed patients, and his success was such that 'the concourse of patients of all kinds which the report of the cures brought together was prodigious'. In fact, the success of these treatments was so great that the priests had to be called in to convince the neighbouring people that they had not been wrought by magic. Moreover, as the result of Sauvages' work, a medico-electrical hospital was founded at the Couvent des Célestins, under the authority of the French Government, for the treatment of epilepsy, catalepsy, and nervous diseases of all kinds. This hospital does not appear to have realized the hopes of its founders. Marat attributed its failure to empiricism and a blind routine.

The second treatise on medical electricity of which any record exists was *De Hemiplegia per electricitatem curanda,*

written by Deshais, and published at Montpellier, 1749. (9) This work was followed two years later by Bohadatsch's pamphlet, *De utilitate electrisationis in arte medica*, published at Prague, 1751. (10)

In England electrical treatment appears to have been first practised by the clerical profession. In 1756 a book entitled 'The Subtile Medium: or, that wonderful power of Nature . . . showing its various uses in the animal oeconomy, particularly when applied to maladies and disorders of the human body . . . ,' was published at Worcester. (11)

This book was written by Richard Lovett (1692–1780), a native of Chalfont St. Giles, Bucks., and a lay clerk at Worcester Cathedral. Lovett treated a large number of diseases, including St. Anthony's Fire, bronchocele, contractions, epilepsy, feet violently disordered, gout, headache, mortification, palsy, rheumatism, sciatica, sore throat, and fistula lachrymalis. His treatment appears to have been very thorough; in reference to hysteria and similar cases, he writes: 'In these complaints it is not to be done by halves; not for a few minutes only (which is sufficient in some others), particularly if it has taken deep root; but the person ought to stand or sit on the electrical stool for an hour in the morning and another in the evening each day; or, if two hours a day cannot be complied with, let it be for two half-hours. This may be practised with some times drawing off sparks; afterwards with some slight shocks, and then if the disorder requires it, to be increased with more. Such proceeding I seldom found to fail of the desired effects.'

In 1780, John Wesley, the great divine, anonymously published a most interesting book, entitled, *The Desideratum; or, Electricity made Plain and Useful. By a Lover of Mankind, and of Common Sense.* (12)

Wesley follows very closely the practice of Lovett, to whom he frequently refers. The most remarkable feature of the book is the fervour with which he appeals for a trial of the curative action of electricity. Wesley, to judge from

his writings, held a very poor opinion of the ideals of the medical men of his time. In a book, which he wrote on the treatment of disease by drugs, entitled *Primitive Physic*, he thus expresses his opinion of doctors: 'Physicians now began to be had in admiration as persons who were something more than human. And profit attended their employ as well as honour, so that they had now two weighty reasons for keeping the bulk of mankind at a distance that they might not pry into the mysteries of the profession. To this end they increased those difficulties by design, which began in a manner by accident. They filled their writings with abundance of technical terms, utterly unintelligible to plain men. They affected to deliver their rules and to reason upon them in an abstruse and philosophical manner. They represented the critical knowledge of anatomy, natural philosophy (and what not? Some of them insisting on that of astronomy and astrology too) as necessary previous to the understanding of the art of healing. Those who understood only how to restore the sick to health they branded with the name of Empiricks.'

In the preface of the *Desideratum*, (12) Wesley has another tilt at the doctors: 'Mr. Lovett is of opinion that "the electrical method of treating disorders cannot be expected to arrive at any degree of perfection till administered and applied by the Gentlemen of the Faculty." Nay, then, quanta de spe decidi! All my hopes are at an end. For when will it be administered and applied by them? Truly, ad Graecas Calendas. Not till the Gentlemen of the Faculty have more regard to the interest of their neighbours than their own. At least not till there are no apothecaries in the land, or till physicians are independent of them.'

Wesley concludes his book with the following sarcastic and impassioned, but thoroughly rational appeal to the medical profession: 'Before I conclude, I would beg one thing (if it be not too great a favour) from the Gentlemen of the Faculty, and indeed from all who desire health and freedom from pain, either for themselves or for their

neighbours. It is, that none of them would not condemn they know not what; that they would hear the cause before they pass sentence; that they would not peremptorily pronounce against electricity while they know little or nothing about it. Rather let every candid man take a little pains to understand the question before he determines it. Let him for two or three weeks (at least) try it himself in the above named disorders. And then his own senses will show him whether it is a mere plaything or the noblest medicine yet known in the world.'

Space does not permit an analysis of Wesley's alleged cures, but there are one or two passages in the book which are especially deserving of attention. The experience of most electrotherapists would lead them to assent to the following statement: 'And yet there is something peculiarly unaccountable with regard to its operation. In some cases, where there was no hope of help, it will succeed beyond all expectation. In others, where we had the greatest hope, it will have no effect at all. Again, in some experiments it helps at the very first, and promises a speedy cure; but presently the good effect ceases, and the patient is as he was before. On the contrary, it has no effect at first; it does no good, perhaps seems to hurt. Yet all the time it is striking at the root of the disease, which in a while it totally removes.'

Among the forty-two experiments which Wesley quotes from Martin's *Essay on Electricity*, the following is of special interest as it foreshadows the experiments of Geissler and Crookes with vacuum tubes: (13)

'If the globe be exhausted of air, and then turn'd, the electric fire will act wholly within the globe, where it will appear (in a dark room) as a reddish or purple flame, filling the whole globe. But this, as the air is readmitted into it, will gradually disappear.'

Though unqualified practitioners, both Wesley and Lovett had a very real and genuine belief in the efficacy of electrical treatment, and their zeal and enthusiasm did a great deal for the early development of this science;

moreover, their work and their writings survived them for many years, and were frequently quoted by their qualified successors. Priestley thus comments on their work: 'This account of the medical use of electricity by Mr. Lovett and Mr. Wesley is certainly liable to an objection, which will always lie against the accounts of those persons who, not being of the faculty, cannot be supposed capable of distinguishing with accuracy, either the nature of the disorders, or the consequences of a seeming cure. But, on the other hand, this very circumstance of their ignorance of the nature of disorders, and consequently of the best method of applying electricity to them, supplies the strongest argument in favour of its innocence, at least. If in such unskilful hands it produced so much good, and so little harm, how much more good, and how much less harm would it possibly have produced in more skilful hands.'

The first treatise on electrical treatment, written in Great Britain by a medical man, was a thesis on paralysis, which J. Smyth Carmichael presented on October 29, 1764, for the degree of Doctor of Medicine at the University of Edinburgh. (14) In this *Testamen Medicum Inaugurale de Paralysi* Carmichael very clearly describes the method of administering the electrical treatment of his time. Before entering into details of treatment, he first quotes the Abbé Nollet (*Mémoires de l'Académie des Sciences*, 1748) to show the effect of electricity in hastening the passage of water through capillary tubes, and its accelerating action on the germination and vegetation of plants.

Carmichael then states that Verratti, of Bologna, and other Italians were the first to use electricity in medicine. The method at first adopted was to insulate the patient, charge him with the electrical current and draw sparks from different parts of his body. Subsequently the introduction of the Leyden jar led to the administration of strong shocks (commotiones fortiores).

The results of treatment showed an increase in the flow of urine (Linnaeus, Zetzel, and Verratti); the onset of diarrhoea (Jallabert); increased secretion of cerumen (Lin-

naeus); an increase in the amount and a prolongation of the menstrual flow (De Haen).

The treatment of paralysis relieved pain and excited involuntary contraction of the muscles (Verratti and Jallabert). The parts from which the sparks were drawn off became hot and red. Nollet in his experiments caused blisters by his sparks, but Carmichael was of opinion that this could not occur in the human subject, because the thinness of the human skin allowed the sparks to escape readily. Sparking of the parotid increased the flow of saliva (Boissier). Strong sparks gave great pain to the sick, greater in the affected than in the healthy parts (Nollet and Morand). The shocks excited contraction in the most insensitive muscles.

Electrization was found to increase the strength, to restore the pristine bloom to the atrophied parts, to render the veins more manifest, and to bring back the natural colour of the skin.

De Haen stated that the electrical force never hurt any one. Carmichael, however, remarks that 'this ought not to be accepted as the general rule, for Verratti has shown that one ought always to guard against the use of electricity when there is any suspicion of latent venereal disease'.

Carmichael concludes the electrical portion of his thesis by quoting two cases of paralysis cured by electricity.

A careful survey of the history of any subject almost invariably reveals the forgotten existence of many facts and fallacies, which many years later are rediscovered and heralded forth as new and original observations. For the past few years no form of electrical treatment has been so extensively practised as that known as 'Ionic Medication'. It is only recently that the absurdity of the claim that drugs can be electrically introduced into the deeper tissues of the body and there exercise their specific action has been definitely exposed. It is very interesting, therefore, to find that Priestley vehemently inveighs against a very similar theory that was in vogue in his time. 'In the course of history', writes Priestley (1775), 'we have seen frequent

instances of self deception, for want of persons attending to all the essential circumstances of facts; but nothing that we have seen equals what was exhibited in the years 1747 and 1748. Mr. Grey's deception was chiefly due to his mistaking the cause of real appearances; but in this case we can hardly help thinking that not only the imagination and judgment, but even all the external senses of philosophers must have been imposed upon. It was asserted by Mr. Privati, of Venice, (who has all the merit of these extraordinary discoveries), and, after him, by Mr. Verratti at Bologna, Mr. Bianchi at Turin, and Mr. Winckler at Leipsick, that if odorous substances were confined in glass vessels, and the vessels excited, the odours and the other medicinal virtues would transpire through the glass, infect the atmosphere of the conductor, and communicate the virtue to all persons in contact with it; also that those substances held in the hands of persons electrified, would communicate their virtues to them; so that medicines might be made to operate without being taken into the stomach.'

'They even pretended to have wrought many cures by the help of electricity applied in this way.' Priestley goes on to relate that a patient with a pain in his side had hyssop applied to it by the advice of his physician; he then approached the cylinder and was electrified. 'The consequence was that he went home and fell asleep, he sweated, and the power of the balsam was so dispersed, that even his clothes, his bed, and chamber all smelled of it. When he had refreshed himself by his sleep, he combed his head, and found the balsam to have penetrated his hair, so that the very comb was perfumed.'

Another patient treated in this way by Privati was no less a person than Signor Donadoni, Bishop of Sebenico. He came to the seance attended by his physician and friends. His lordship was seventy-five years of age, and had experienced pain in his hands and feet for many years. Owing to gout, he could not bend his knees or move his fingers. 'In this deplorable condition, the poor old bishop

implored Privati to treat him by electricity. Privati filled a glass cylinder with discutient medicines, and managed it so that the electric virtue might enter into the patient, who presently felt some unusual commotion in his fingers. After two minutes treatment, his lordship opened and shut both his hands, gave a hearty squeeze to one of his attendants, got up, walked, smote his hands together, helped himself to a chair and sat down wondering at his own strength, and hardly knowing whether it was not a dream. At length he walked out of the chamber, down stairs, without any assistance, and with the alacrity of a young man.'

Privati and his followers were probably examples of investigators whose enthusiasm had outrun their discretion; but an undoubted charlatan of this period was a certain Professor Boze, who practised a sort of Maskelyne and Cooke role. He initiated a new form of electrical treatment which he termed 'Beatification'. The patient was seated on a large cake of pitch and electrified; in a short time he was surrounded by flames and smoke, and a halo of electrical breeze adorned his head.

Dr. Watson, who had already disproved the extraordinary claims of Privati, exposed the fraud in this case by showing that the professor, before his experiments, clothed himself in a suit of armour provided with a number of points and bosses.

It was not long after Wesley and Lovett started their electrical treatment that electrical quackery made its appearance in this country. James Graham (1745–94), of Edinburgh, affords a striking example of an electrical quack, a class that still flourishes in this country, tolerated by an indifferent or indulgent government, and largely patronized by a gullible public.

Graham was the son of a saddler at Edinburgh, and is said to have studied medicine under Monro, Cullen, and Whytt at that university.

There appears to be some doubt whether he took his degree in medicine. His pamphlets are signed 'James Graham M.D.', but the *Dictionary of National Biography*

states 'It is doubtful whether he qualified at Edinburgh, where, in 1783, he was described as the person calling himself Dr. Graham'.

Graham practised as an aurist and oculist in America, and, perhaps, during a two-years' stay at Philadelphia, 1772–4, he may have acquired his electrical knowledge from a study of Benjamin Franklin's work. But though he may have gained some acquaintance with electricity from the experiments of Franklin, he certainly did not learn his quackery from that great man, for Franklin was most cautious and reserved in his references to medical electricity. In a letter to Sir J. Pringle, read at the Royal Society, January 12, 1758, Franklin writes, 'he never knew any permanent advantage from electricity in palsies', and goes on to say that, 'perhaps some permanent advantage might be obtained if the electrical shocks had been accompanied by proper medicine and regimen, under the direction of a skilled physician'.

On his return to England, Graham practised electrical treatment at Bath, Bristol, and London. In 1779 we find him at Aix-la-Chapelle, where he treated Georgina, Duchess of Devonshire. The patronage of this duchess appears to have been very useful to him, and in the autumn of the same year he established himself at the 'Temple of Health', Adelphi House, London. He fitted up this establishment with most elaborate electrical machines,including an electrical throne insulated upon glass pillars; he claimed to have spent £10,000 upon the installation. This palace did not for long satisfy his ambitions, and he soon opened the 'Temple of Health and Hymen' at Schomberg House, Pall Mall. It was here that he acquired another claim to fame by becoming associated with the notorious Emma Lyon, afterwards the celebrated Lady Hamilton, the companion of Lord Nelson. Graham is said to have exhibited the 'frail Emma' as the Goddess of Beauty, and to have utilized her as a nude model for his lectures on health.

Horace Walpole, in his *Letters*, writes of Graham: 'The most impudent puppet show I ever saw, and the mounte-

bank himself the dullest of his profession, except that he makes the spectators pay a crown apiece'. Southey describes him as 'half enthusiast, half knave'.

Graham's method of electrical treatment consisted in placing his patients, either in baths, or on a 'Magnetic Throne', through which electrical currents were passed. His chief speciality was the treatment of sterility; its cure was effected by sleeping in the 'Celestial Bed', at the modest fee of £50.

A copy of the *Morning Chronicle*, Thursday, April 24, 1783, contains the following advertisement of Graham's establishment:

'Temple of Health and Hymen, Pall Mall. Dr. Graham begs respectfully to inform the Public that this evening, and every evening this week, he will, at the very earnest request of many Gentlemen of the Navy and Army, lately arrived from abroad, deliver his very celebrated Lecture on Generation, &c. . . . Admittance two shillings. A valuable pamphlet will be given gratis to every Lady and Gentleman as they enter the Temple. Patients are electrified and Dr. Graham may be consulted as usual.'

Graham was an early exponent of the virtue of the mud bath, a form of treatment of which he showed his personal appreciation by burying himself in the earth for hours at a time. On one occasion he carried out this treatment in company with a young lady from Newcastle.

Having first powdered their heads, they were buried in the earth up to their chins, and were likened by a spectator to two blooming cauliflowers. Graham decried flesh-eating and alcoholic excess; he states that he never ate more than sixpennyworth of food in a day. He advocated cold bathing, open windows, and sleeping on hard mattresses. He asserted that all diseases were caused by wearing too many clothes. He appears to have carried this idea to extremes, for Southey records that 'he would madden himself with opium, rush into the streets, and strip himself to cloathe the first beggar he met'.

Towards the end of his career Graham suffered from

religious mania, and at Edinburgh was confined to his house as a lunatic. Had Graham lived at the present time he would probably have been a leading Christian Scientist, for in one of his later pamphlets he describes himself as 'formerly a physician, but now a Christian Philosopher'.

In 1778, Dr. Robert Steavenson, of Edinburgh, presented his thesis, *De Electricitate et Operatione ejus in Morbis Curandis*. (15) This dissertation is little more than a résumé of the earlier writers, and its chief interest lies in the fact that a descendant of the author, Dr. W. E. Steavenson, of St. Bartholomew's Hospital, the first medical electrician of that institution, wrote a thesis on the same subject and under the same title for the M.D. degree of the University of Cambridge, 1884.

Jean-Paul Marat (1743–93), scientist, revolutionist, oculist, pulmonary specialist, and electrotherapist, forms one of the most interesting figures in the history of electrotherapy. This man of many parts spent ten years in London, practising during a portion of the time in Conduit Street, Soho. He frequently attended the meetings of the London scientific societies, and on June 30, 1775, was admitted to the degree of M.D. at St. Andrews. It was during his stay in London that he published his paper, *An Enquiry into the Nature, Cause, and Cure of a Singular Disease of the Eye*.

Marat does not appear to have practised electrotherapy during his stay in England, but shortly after his return to France he took part in a disputation, held by the Academy of Lyons, on the value of electricity in medicine. This disputation appears to have been rather acrimonious, for the judges, in awarding the prize to the Abbé Bertholon, for his paper entitled 'The Influence of the Electricity of the Atmosphere on Diseases', expressed their regret that the Abbé had not been more courteous to his distinguished opponent, Marat.

Bertholon made extravagant claims for the use of electricity in all diseases, basing his theories on pure empiricism

rather than upon actual experience. He contended that all diseases were due either to a deficiency or an excess of the electric fluid. The former cases he treated by the electric bath, the latter by drawing off the excess from the back of the hand of the electrically charged patient. A somewhat similar theory to that of Bertholon, and one but little less absurd, was recently advanced in this country by an electrical engineer, and, like the absurdities of the past, it was not lacking in followers, even among medical men. Marat would have nothing to do with such nonsense; he showed definitely in what diseases electricity should be used, he determined the method of its administration and he defined the mode of its action. Marat, indeed, made no small claims for his book on electrotherapy, *Mémoires sur l'électricité médicale* (1784): (16) 'One will not find in this publication any hypothesis, any uncertain experiment, any doubtful principle, any hazardous conclusion; it is upon facts alone, but upon simple and constant facts that all my reasoning is based.' Marat, to some extent at any rate, justified these ambitious claims, for his work was certainly on far more scientific lines than the writings of any of his predecessors, or even, one might add with equal truth, than the publications of many of his successors.

Marat, in his book, yields appreciative testimony to the work of Franklin, but he rejects the idea that the atmospheric electricity has any effect upon the human economy. He states that artificial, as opposed to atmospheric electricity can alone be of any use. From the electric bath he only obtained moderate results. He studied the effects of sparks and shocks, applied in accordance with the practice of his time. He conducted experiments on animals to ascertain the effects of sparks. As the result of his experiments, he concluded that of the fluids of the human body the urine was the best electrical conductor; next in order came the bile, the blood, the lymph, and the synovial fluid.

Marat held that electricity was justified in the treatment of external indolent tumours, oedematous engorgement of the limbs, cutaneous eruptions, paralysis, hemiplegia,

rheumatism, sciatica, and the colic of painters, founders and enamellers. He insisted that the duration of a treatment should be definitely fixed, that there should be a dosage of electricity as well as of other medicines. A seance should last for twenty minutes or more; it should be repeated three or four times a day. Strong shocks should not be used at all; they should be weak at first and should be gradually increased in strength.

Marat's writings, whether political or scientific, reveal him as a man of overwhelming self-conceit, obsessed by the idea that the hand of everyone was directed against him. A letter to his friend, Philippe Saint-Laurent, at about the time he was writing his book on electrotherapy, November 20, 1783, sheds an interesting sidelight on this side of his character. In this letter he states that 'he met with great success in his practice as a physician, that he had the good fortune to restore to health many sick persons of distinguished rank, whose lives had been despaired of by their physicians. The fame of his cures drew to him a prodigious crowd of sick persons; and his door was continuously assailed by the carriages of patients who came to consult him from every quarter.' He goes on to lament that 'His success gave umbrage to the doctors of the faculty, who calculated with sorrow the large amount of his profits. They consoled themselves by slandering him; and, though a large number of persons whose friendship for him was founded on esteem took up his defence, their voices were drowned by the clamour of his opponents. Disgust, inseparable from the practice of medicine, made him sigh once more for the retirement of his library; he gave himself up entirely to his favourite studies. Could he have foreseen that he was going to make himself a fresh cause for envy?'

Up to the period at which we have now arrived, the only form of electricity known was that obtained from friction. According to popular tradition, a certain Madame Galvani, the wife of Aloysius Galvani, Professor of Anatomy at

Bologna, was in ill health; she was consequently ordered by her physician to undergo a diet of frog soup, a delicacy of which she is said to have been very fond. It so happened that in the neighbourhood of the frogs laid out on the table in preparation for the meal, one of the professor's assistants was turning a frictional machine.

Madame Galvani, to her great surprise, noticed that, when a spark was elicited from the apparatus, the frogs' legs became contracted, distorted, and apparently endowed with life. The professor was immediately summoned to witness the phenomenon, which so impressed him that he immediately proceeded to perform a series of experiments, which are said to have had as much influence on the progress of science as the discoveries of Galileo and Newton. Unfortunately for the credit of this story, but fortunately for the reputation of Galvani, who has been said by some writers to have been ignorant of electricity at the time he made his discovery, his manuscripts were collected after his death by M. Gherardi and were published by the Academy of Science of Bologna. Among these papers was a draft in the handwriting of Galvani, dated November 6, 1780, in which electricity is dealt with in relation to the excitation of contraction in the legs of frogs. In another paper, dated September 20, 1786, entitled 'Electricity of Metals', Galvani describes the contraction that occurred in the legs of a recently killed frog when the muscles and nerves were touched by an arc formed by two dissimilar metals. (17)

It appears, according to Matteucci, in his 'Treatise on the Electrophysiological Phenomena of Animals', that the celebrated entomologist Swammerdam showed an experiment of a similar character to the Grand Duke of Tuscany in 1678. This experiment is thus described: 'Into a cylindrical tube of glass was placed a muscle, the nerve of which was enveloped with a small silver wire, in such a manner that it could be raised without injury. The first wire was brought through a ring, bored in the extremity of a small copper support, soldered to a sort of piston or

partition; but this small silver wire was disposed of in such a manner that, on passing between the glass and the piston, the nerve could be drawn by the hand so as to touch the copper. The muscle immediately contracted.' Swammerdam's experiment was apparently lost sight of and was unknown to Galvani.

Galvani's great work, *De viribus electricitatis in motu musculari commentarius*, 1791, is divided into three parts, dealing respectively with the influence of (1) artificial, (2) atmospheric, and (3) animal electricity in exciting muscular contraction. (18)

It is evident that the author foresaw the application of his discovery to the treatment of disease; for in the opening paragraph he states that he has undertaken his arduous task and has performed a large number of experiments with a view to its practical application, and also to make its use safer in the treatment of diseases.

Galvani at first maintained that the electricity came directly from the muscles and nerves themselves, and in the flush of his initial success he is stated to have believed that he had discovered the origin of life. At this period Alessandro Volta (1745–1827), Professor of Natural Philosophy at Pavia, opportunely came on the scene and was able to show that the current came from the contact of two dissimilar metals.

As the result of this conclusion, Volta was led to construct his famous Voltaic Pile, consisting of alternate discs of copper and zinc, separated by wet strips of cloth. The announcement of this discovery was made by Volta in a letter to Sir Joseph Banks in 1800.

In the following year Volta visited Paris and showed his instrument to Napoleon at the French Academy of Science. Napoleon, on seeing Volta's pile in action, is related by Chaptal to have exclaimed: 'Voilà l'image de la vie: la colonne vertébrale est la pile, la vessie le pôle positif, et le foie le pôle négatif'.*

* It is interesting to compare Napoleon's impression with the view arrived at by the well-known American surgeon, Mr. G. W.

Volta subsequently discarded his pile for the 'Couronne de Tasses', which he designed in its place. This instrument consisted of a large number of glass cups, filled with salt and water, or dilute sulphuric acid. In each of these vessels were placed a zinc and copper rod; the zinc rod (–) in one vessel was connected with the copper rod (+) in the next; in this way a battery of cells, in series, was obtained, practically of the same character as the present-day battery.

These experiments of Galvani and Volta rendered possible the far-reaching experiments of Sir Humphry Davy in electro-chemistry; they also enabled Oersted, of Copenhagen, in 1820, to demonstrate the deflexion of the magnetic needle by the electric current, an experiment which in turn led to the invention of the induction coil and the dynamo. To these instruments the origin of all the modern theories and applications of electricity may be traced; but the steps by which these developments have been arrived at is beyond the scope of this book.

When we trace the development of electrotherapy from Galvani's discovery, we find that the apparent restoration of function in frogs' legs, which occurred under the influence of the galvanic current, naturally led to the current being first applied to the apparently dead.

As early as 1792 galvanism was recommended as a means of distinguishing real from apparent death. Valli about this time claimed to have restored to life, by means of galvanism, fowls which had apparently been drowned. Therapeutical experiments were also at this period performed on patients at the University of Jena by Professor Loder, and Drs. Bischoff and Leickenstein recorded the

Crile, in his book, *A Bipolar Theory of Living Processes*, 1926. 'If our conception be true, then among the positive or "nuclear" tissues there must be a tissue of the highest potential of all, and since oxidation determines potential, we are justified, on the basis of experimental studies, in considering that *the brain is the positive pole* in the organism. It remains to give the evidence on which we base our assumption that among the "cytoplasmic" or negative tissues, the liver had the lowest potential—is the negative pole of the organism.'

cure of two cases of amaurosis, and improvement in a case of hemiplegia.

In 1801 Dr. Grapengeisser, of Berlin, published a treatise on the therapeutic effects of galvanism, and recommended its use in weak sight, amaurosis, deafness, rheumatism, and sciatica. Aldini, of Bologna, the nephew of Galvani, published in 1804 his *Essai théorique et expérimental sur le galvanisme,* Paris, in which he recommended the use of galvanism for disorders of the mind, neuroses, and diseases of the organs of special sense. (19)

Partly owing to defective apparatus, but chiefly on account of its failure to fulfil the preposterous claims of its too enthusiastic advocates, galvanism declined for a time into disuse. A revival in the form of electrical acupuncture took place about 1825. In that year Sarlandière published his *Mémoires sur l'électroponcture considérée comme moyen nouveau de traiter efficacement la goutte, le rheumatisme, et sur l'emploi du moxa japonais en France,* Paris. (20) A work by Majendie appeared a year later, entitled *On Galvanism, with Observations on its Chemycal Properties and Medical Efficacy in Chronic Diseases,* London. (21)

Sarlandière employed two steel or platinum needles, introducing them as in acupuncture, or, as it was then called, acupuncturation, and connecting them respectively with the opposite poles of the battery. Majendie was a bold operator, and his practice was to introduce the needles directly through the eyeball on to the optic nerve, to which he applied the current. It is related that in this way he accomplished some remarkable cures; but, as sometimes happens even now in the relation of modern surgical marvels, nothing is said of the occasional disastrous failures resulting from so drastic a procedure.

The discovery of the induction coil by Faraday, in 1831, was attended by far less sensational, but by far more valuable clinical results than those which immediately ensued on the publication of Galvani's work.

Five years later, in the autumn of 1836, an electrical

department was opened at Guy's Hospital, a room being set apart for the administration of electricity under the direction of Dr. Golding Bird, with clinical clerks to record the cases. Dr. Golding Bird remained in charge of the department for eight years, when he was succeeded by Dr., afterwards Sir, William Gull. Though this was the first electrical department established in England, electrical treatment had been practised in the Royal Infirmary, Edinburgh, many years previously; for Dr. Whytt, in his book, *The Cause of Nervous Disorders*, published in 1764, records the case of a patient in that institution, 'who felt a remarkable uneasiness through his whole body, when it was charged with the electrical fluid by means of a wire held in the hand, although there was no other shock given him'. (22)

Dr. Golding Bird's lectures 'On Electricity and Galvanism in relation to Physiology and Therapeutics', delivered to the Royal College of Physicians in the spring of 1847, mark a distinct advance in the recognition accorded to electrotherapy by the medical profession. These lectures were published in book form in 1849. This charmingly written book commences with a philosophical discussion on the electrical methods in use in the author's day, and concludes with an account of his personal experience of the results obtained, chiefly in connexion with the work at Guy's Hospital. (23)

Dr. Bird complains of the position of electrotherapy in his time in much the same terms as we frequently hear used to-day:

'Electricity has been by no means fairly treated as a therapeutical agent; for it has either been exclusively referred to, when all other remedies have failed—in fact, often exclusively, or nearly so, in hopeless cases—or its administration has been carelessly directed, and the mandate, 'Let the patient be electrified', merely given, without reference to the manner, form, or mode, of the remedy being for an instant taken into consideration. Conscientiously convinced that the agent in question is a no less

energetic than valuable remedy in the treatment of disease, I feel most anxious to impress its employment upon the practical physician, and to urge him to have recourse to it as a rational but fallible remedy, and not to regard it as one capable of effecting impossibilities.'

Dr. Bird mentions the success which attended the use of faradism by a skilled obstetrician in cases of uterine inertia; he alludes to the scepticism expressed by the famous obstetrician, Dr. Simpson, of Edinburgh, in respect to this treatment. But Dr. Bird prefers to pin his faith to the facts recorded by Drs. Lever and Radford rather than to the theories of Dr. Simpson. Faradism is also recorded as having been successful in the control of post-partum haemorrhage.

Faradism is referred to on the testimony of others as having benefited incontinence of urine and atony of the bladder.

Dr. Bird mentioned that he had never seen electricity successful in cases of paralysis attended with permanent contractions. He advocated the use of static sparks in lead palsy, and recommended various forms of electricity in the treatment of hysteria, chorea, amenorrhoea, tonsillitis, catalepsy, &c. 'In the treatment of amaurosis,' he says, 'I have seen it employed in the hospital under all forms of this disease, and regret that I have never been able to observe the slightest benefit in whatever way it has been employed. In deafness, also, it has been greatly lauded, but I have seen little which can bear out the commendations accorded to it by some writers.'

Dr. Bird is most enthusiastic over the treatment of indolent wounds by the 'electric moxa'. The term 'moxa' is of Chinese derivation, and signifies 'any substance burnt on a disease part, as a cautery'. The reference to the Japanese moxa in the title of Sarlandière's book on galvano-acupuncture (1825) suggests the possibility that research might reveal the practice of this method in China in ages long ago. The electric moxa comprises the employment of a zinc and a copper plate connected by a wire,

namely, an electric couple. Under the zinc plate (the active electrode) electrolytic action occurs with the formation of zinc oxychloride on the surface of the wound causing a more or less deep slough according to the strength of the current and the duration of its employment. When a wound did not previously exist blisters were first induced to overcome the high resistance of the skin.

In the case of the silver plate (the indifferent electrode), well moistening the skin with salt and water was usually all the preparation required. In the appendix of the book there are some interesting notes of the employment of this method in the treatment of the Crimean wounded by Mr., afterwards Sir, Thomas Spencer Wells, the celebrated surgeon, then serving as a surgeon in the navy. About sixty cases of indolent wounds, ulcers, fistulae, &c., are so recorded.

Probably as the result of Dr. Bird's lectures, the Pulvemacher, and later the Harness electrical belts were foisted upon a credulous public during the latter half of the nineteenth century. These apparently were a most remunerative form of quackery. The belts consisted of metal discs on the plan of Dr. Bird's moxas, but as the preliminary production of blisters would not have conduced to a speedy sale of the apparatus, the electrical resistance of the skin was ignored, with the result that the deluded victims suffered in pocket only and no wounds or sores were occasioned. A large number of medical men of the time, among whom are said to have been Sir Richard Quain and Sir Andrew Clark, testified to the efficacy of these electric belts, and, owing to their ignorance of electricity, contributed to the imposture.

It was the discovery of Faraday that led to the electrical work of the most famous and illustrious of all medical electricians, Duchenne, of Boulogne, 'the man who has played a preponderating part in the researches and discoveries upon which the edifice of neuropathology has been erected'.

In 1849, Duchenne made his first, and in 1852 his second

communication to the French Academy of Science: 'A Critical Examination of the Instruments of Induction, from the point of view of their application to Physiology, Pathology, and Therapeutics'. (24) In 1855 he published his book of 926 pages, *De l'électrisation localisée.* (25)

Duchenne relied chiefly on faradism: 'Of the three forms of electricity, induced electricity (faradism) is the best for muscular electrization, especially as it can be practised frequently and for a long time. . . . In its application to physiology, pathology, and to treatment, this method of electrization has surpassed my expectations in yielding scientific and practical results of the highest importance.'

Duchenne was of opinion that there was a difference in the physiological action of the primary and secondary currents, but Becquerel pointed out that the variation in physiological effects of the two currents was merely the result of their difference in voltage.

Drs. Neef, of Berlin, and Masson, of Paris, are said to have been the first to apply faradism to the treatment of disease; but it is certainly to A. Tripier, of Paris, who began writing of the treatment of the diseases of women by faradism in 1859, that we owe the modern type of faradic coil. In fact, it may be said that, with the exception of the condenser added by Fizeau, no definite improvement has been made in this instrument since 1865, when Tripier showed to the French Academy of Science a series of coils with different windings, both in their primaries and their secondaries, and fitted with an interrupter, the vibratory rate of which could be varied at will.

Tripier, moreover, shares with Apostoli the credit of being the first successfully to apply electricity in a rational and methodical manner to the treatment of uterine fibroids. Tripier relied in such cases on the faradic current, and Apostoli preferred galvanism.

We have now reached a period when the history of the past merges into the record of the modern development of electrotherapy; the recent history of high-frequency

currents, diathermy, actinotherapy, &c., will be more appropriately dealt with under their respective sections.

There still remains, however, to be considered the origin of the fallacy that drugs can be introduced, by means of the galvanic current, deeply into the tissues and can there exercise their specific action: the so-called 'Ionic Medication'.

It is generally thought that this treatment was first practised by Leduc, of Nantes, and that it was introduced into this country by Dr. Lewis Jones. Historical research shows that this method was used in this country by Sir Benjamin Ward Richardson in the year 1858, under the name of 'Voltaic Narcotism'.

In October, 1858, Richardson produced a local anaesthesia as the result of applying a solution of morphia under the positive pole of the current; and he published the results of these experiments in the *Medical Times and Gazette* of February 12 and June 25, 1859.

Richardson subsequently substituted the following preparation for the solution of morphia.

Tinct: Aconiti 3ij
Extr: Aconiti gr. xx
Chloroformi 3iij

Applying this solution under the positive pole, and passing a continuous current for eleven minutes, he obtained local anaesthesia in a dog's leg, enabling the limb to be amputated with no evidence of pain except when the bone was sawn through. A child's naevus was painlessly removed, teeth were extracted, and a hernia operated on by the same technique.

It is probably due to the exclusive employment of the positive pole as the active electrode for these experiments, that the term 'cataphoresis' came to be applied, and is still used at such places as hydros and electrical institutes as synonymous with the term 'Ionic medication'. It is remarkable that such drugs as chloroform and the alcoholic tinctures were employed, for they are very deficient in ions and are hence very feeble conductors of electricity.

The chloroform and other agents were merely absorbed

through the skin after it had been inflamed by the high voltage necessary to force any current through it owing to the application of these non-conducting solutions. Wagner, at the time, pointed out the non-conducting properties of chloroform, and Waller also showed that the insensibility induced was due merely to the absorption and not to the electrical introduction of the chloroform, that the procedure was painful, and resulted in inflammation and destruction of the skin.

Richardson subsequently withdrew the claims he had made for the practical value of the treatment.

In taking a general survey of the development of electrotherapy from the earliest times, we cannot fail to be struck by the extremely undulating character of its progress. In almost every instance the sudden advance, consequent upon a new discovery, is followed by a nearly corresponding set-back. These failures in the realization of our early hopes are often, to some extent, due to the exaggerated zeal of too enthusiastic investigators; but a careful study of the circumstances will reveal the fact that they are mainly attributable to the immediate exploitation of any new discovery by unqualified and unprincipled quacks. In a paper on the history of electrotherapy in Great Britain that I contributed some years ago to the *American Journal of Electrotherapeutics*, I wrote as follows: 'The science and practice of electrotherapy can never develop to their full efficiency until they receive their due recognition as an important branch of the healing art, until they are efficiently taught in our universities and schools of medicine, and are placed in the schedules of our examining boards'. (26)

To this opinion I still adhere; for it is manifestly absurd to suppose that a highly specialized art and science, such as electrotherapy, which requires for its effectual administration an intimate knowledge of anatomy, physiology, electricity, and pathology, can be adequately practised by any mere electrician or masseuse. As the Greek philoso-

pher laid down: 'If we wish to master any art or to gain a scientific knowledge of it, we must study its general principles, and make ourselves acquainted with them in the proper manner'. (27)

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# PART II

# THE THERAPEUTIC ACTION OF CURRENT ELECTRICITY

## CHAPTER I

## THE GENERAL PRINCIPLES OF ELECTROTHERAPY

THE application of electricity as a curative agent appears in the past to have been regarded as the employment of a mysterious force only capable of administration in an empirical manner, and until recent years little change appears to have occurred in the views held by the medical profession in regard to the value of electricity as a therapeutic agent. The words of Dr. Golding Bird are as true and as applicable to-day as when he delivered them at the Royal College of Physicians in 1847: 'Electricity has been by no means fairly treated as a therapeutic agent; for it has either been exclusively referred to, when all other remedies have failed—in fact, often exclusively, or nearly so, in helpless cases—or its administration has been carelessly directed, and the mandate, 'Let the patient be electrified', merely given, without reference to the manner, form, or mode, of the remedy being for an instant taken into consideration'.

Electricity still remains a 'rational but fallible remedy', and is still incapable 'of effecting impossibilities'. But it is by no means an empirical remedy; its mode of action is indeed more capable of explanation and visualization than many forms of drug therapy. Electricity has no direct or specific action on disease; it merely supplies us with that energy or force from which by means of suitable instrumentation and the correct methods we obtain the required therapeutic energy.

It is, of course, unnecessary seriously to consider the

idea formerly prevalent, and not as yet entirely obsolete, that a patient after an electrical treatment is charged with that mysterious, subtle and vital force, electricity, which so invigorates and restores every part of his body that he feels an entirely new man.

Such ideas as these only belong to the advertisement pages of the newspapers, where they are impressively conveyed by the illustrations of the radiant energy emitted by the prospective dupe.

There are, however, other theories, widely held, which it is difficult to reconcile with the negative evidence of the action of externally applied currents upon the intrinsic currents of the body. Most notable of these is the explanation of the action of electrotherapy by the theory of its action on the various cells and tissues of the body by polarization (constant current), or by condenser effects (interrupted currents).

If these phenomena of polarization or of condenser effects occur within the body with sufficient energy, as the result of externally applied currents, to modify directly the cellular activity of the body, why is it that these phenomena are always beneficial, and how is it that the normal functions of the body are not materially interfered with? Whilst we employ the strongest currents of which we make use, the bodily functions are carried on without the slightest apparent modification; speech, thought, movement, digestion, &c., are all unaffected in the slightest degree, either during or after an electrical treatment.

We are, no doubt, able indirectly by means of externally applied currents to modify cellular activity, to excite muscular contraction, &c.; but these are the consecutive effects of the heating action, the ionic bombardment, and the ionic concentration induced by the externally applied currents. There is no evidence that we can produce polarization or condenser effects deeply within the body as the result of externally applied current electricity.

There is only one way by which we can profoundly modify or interfere with the bodily functions, and that is

by the abrupt application or interruption of the constant current.

In this case, owing to their relatively high velocity, a sudden concentration of hydrogen ions occurs, and may inhibit the action of the heart or respiration, and so bring about the death of the patient, if the current is of sufficient strength and duration.

From the point of view of the electrotherapist, the problem is not so complicated as at first sight it might appear to be: fortunately the very involved and difficult problems of electrical changes in living tissues belong to the physiologists and biochemists and not to the electrotherapist.

For the practical purposes of electrotherapy it is sufficient to regard the human body as an electrolyte of high conductivity enclosed within a covering of high electrical resistance. The skin with its high resistance, varying from about 500 to 2,000 ohms, constitutes this covering; and the blood serum with its high content of hydrogen and hydroxyl ions, pervading all the tissues, bathing and surrounding all its cells, affords an uninterrupted and connected path of high electrical conductivity throughout the body for the externally applied currents.

If then, as regards externally applied currents, we may regard the body as a uniform highly conducting electrolyte enveloped in a covering of high electrical resistance, it is clear that, on such a hypothesis, no polarization and no condenser effects can occur except in the neighbourhood of the skin; and the body cells, surrounded on all sides by such an electrolyte, will not be affected by any polarization or condenser effects as the direct result of the application of these currents.

In what manner, then, can the externally applied currents of electrotherapy produce their beneficial effects?

This question will be more fully dealt with under the sections concerned with the different forms of current; here it is only necessary to summarize the general principles which govern their actions.

Electric currents, whether generated within the body or

externally applied, are carried solely by the electrically charged particles termed ions. Electrons, free from the electrically charged atoms with which they combine to form these ions, do not exist within the body.

These ions may be positively or negatively charged. If, in the process of their formation (ionization), they have been deprived of one or more electrons, they become positively charged. If, on the other hand, they have acquired an additional electron, they have become negatively charged. Under the influence of an electrical potential, a double procession occurs. The negatively charged ions move up towards the positive pole (anions). The positively charged ions move down towards the negative pole (kations).

Whilst the applied current remains at a constant strength, the movement of the positively charged ions at any point within their path is equal to and is balanced by an equivalent movement of the negatively charged ions in an opposite direction.

The electrostatic force exercised by such a procession of oppositely charged ions inhibits the ions conveying the current from entering into any chemical combination. Hence it is that in an electrolyte, as the result of the passage of the current, no chemical change or combination takes place except at the terminal poles, where the ions yield their electrical charges and enter into combination with the ions which yield up opposite charges. In other words, on arriving at the skin or mucous membrane surface, the electrical charges of the electrolytic ions are 'given up to the electrode, which conveys them away by common conduction, while the atoms are crowded together in such a way that they are glad to combine with each other and escape'.

By the chemical products thus formed, the surface of the skin or mucous membrane may be destroyed by the action of a caustic salt, such as the oxychloride of zinc when metallic zinc is applied as the positive pole, or when a solution of a pad soaked in a solution of a zinc salt is

similarly applied. Or the nerve endings beneath the epidermis may be merely stimulated when the pads are moistened with a less irritating solution. In this manner, by the action of the constant current, we possess the means of destroying superficial morbid growths or septic processes; or, by the employment of less caustic solutions, we can obtain a reflex stimulation by means of the cutaneous nerve endings, and this has consecutive effects on the whole organism of a most important and far-reaching character.

The electrotherapist, in the course of his work, must often be struck by the fact that methods, utterly divergent in their physical character, are frequently followed by identical or very similar results.

For instance, such entirely different agents as the static charge, concentrated salt baths, general galvanism, exposure of the naked body to the fresh air, spray douches, contrast baths, and many other physical stimuli, all produce an improvement of a very similar nature both in the general health and in local conditions. All these methods, apparently so different in character, have but one factor in common, namely, the application of external stimuli to the skin and its nerve endings. It is logical to infer that this constant concomitant factor must bear a causal relationship.

Approaching this subject from a different angle, balneologists have explained many of the effects of hydrology in a similar manner.

A most instructive paper by the late Dr. Sonntag, 'Discussion on the Vagus and Sympathetic Nerves and their relation to Climate and Hydrology', very ably deals with this point of view from the standpoint of the balneologist. (1)

Dr. Sonntag based his conclusions largely upon the lessons taught by a study of comparative anatomy and comparative physiology of the action of the sympathetic and vagus nerves:—

'Many of the effects of climate, which has greatly modi-

fied the character and distribution of animal life in the past, are due to the action of stimuli of temperature, light and variations in barometric and hydrostatic pressure on the cutaneous nerve endings. And the effects of hydrotherapeutic measures are due to physical agents acting on the same structures. Impulses are set up which travel by way of the afferent nerves to the lower nerve centres. Some reach the higher centres, and Professor Elliot Smith believes that the large size of the human brain is partly due to the existence of innumerable nerve endings in the skin. Fortescue Fox states that these impressions influence mental processes to a considerable extent. Fresh stimuli pass out from the nerve centres in different directions:—

(1) By way of the vagus and sympathetic nerves to the organs.

(2) Through the sympathetic nerves to the cutaneous blood-vessels and endocrine organs. The changes in the calibre of the cutaneous arterioles produce secondary changes of an opposite nature in the viscera.

Afferent impulses also pass from the various organs to the nerve centres through the vagus and sympathetic nerves. The result of all these actions is a change in metabolism, which varies in character in accordance with the nature of the climatic and hydrotherapeutic stimuli. The various routes for the impulses are shown (see figure 1).

It is common knowledge that many of the internal organs have an automatic activity which can be altered in many ways by extrinsic stimuli acting through the vagus and sympathetic nerves; and the effects of climate and baths are partly or entirely due to such impressions.' (1)

To the stimuli quoted by Dr. Sonntag, the effects produced on the nerve endings of the skin by the direct and indirect action of electricity and ultra-violet radiation, can obviously be added.

By the reflex action of such stimuli, when applied to the whole or the greater part of the surface of the body, the general constitutional effects of these methods are largely due.

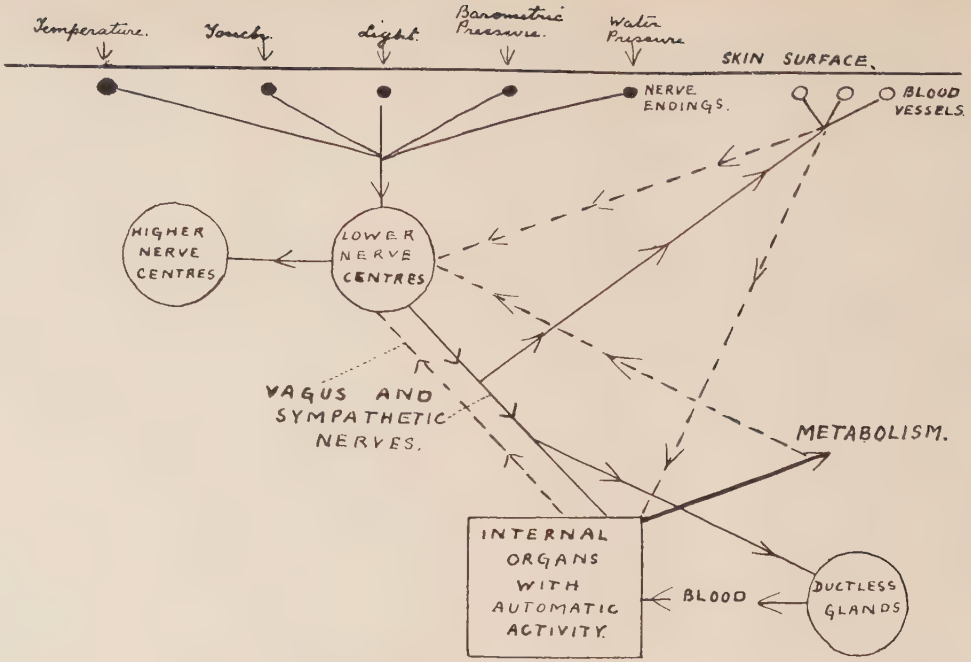


FIG. 1. Sonntag's Scheme illustrating the paths of afferent nerve impulses.
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When, as in local galvanism, or in the local application of ultra-violet radiation, or other such stimulus, we treat a joint or other part of the body, a local vascular dilatation is obtained in the part treated, and a vasoconstrictor effect is brought about in other parts of the body.

In this manner an increased blood supply is obtained in the part treated, partly as the result of the local vaso-dilatation, and partly from the increased blood pressure in the other parts of the body which results from this reflex action. These reflexes are known as the 'Reflexes of Löven', by whom they were experimentally demonstrated in 1866.

When we consider the wide distribution and ramification of these afferent nerves, it must be evident that the explanation of the consecutive effects, resulting from their electrical stimulation, is no simple matter. The most evident effect, as seen by the electrotherapist, is an increased blood supply to the part treated, and hence an improved nutrition and increased resisting power in that part.

Such consecutive effects serve to explain the beneficial action of electrotherapy in many cases. Moreover, by means of the interpolar action of the galvanic current, we are able, to some further extent, to increase the temperature, and hence the blood supply of the part treated, and in this way again we beneficially influence its nutrition.

The phenomena attending the administration of interrupted currents are due to the relative velocity of the hydrogen ion and the resulting hydrogen ion concentration. As a writer on 'Textile Science' recently remarked: 'This hydrogen ion concentration seems to be the password in all fields of science at the present moment'. This is certainly the case as regards electrotherapy, for on no other basis can we satisfactorily explain the action of the faradic, sinusoidal, or any of the other forms of interrupted current of low frequency.

When we interrupt an electrical current at periods of low frequency, we induce a recurrent concentration of hydrogen ions, which may be utilized for the excitation

of muscular contraction, thus enabling us to fulfil a frequently recurring indication in the treatment of such conditions as obesity, paresis, &c. Or, again, by the stimulus which such a recurrent hydrogen ion concentration imparts to the tissue cells, the metabolic activity of various parts of the body may be considerably increased.

By further increasing the frequency of the interruptions of the current, we ultimately reach a point at which this hydrogen ion concentration is neutralized by a corresponding hydroxyl ion concentration, and vice versa, before either has time to become effective.

In the case of these high-frequency currents, the only effects produced are those due to the bombardment and friction of the oscillating ions, and of these effects the most obvious is the production of heat throughout the path of the current. We are in this way furnished with the means for heating the deeper structures of the body.

The relaxation of spasm and tension resulting from this thermal energy enables us thereby to relieve pain in any part of the body. Moreover, as the further indirect effect of this heat energy, we have, in the application of diathermy, the means of increasing the activity of the ductless glands. By the concentration of this heat upon small areas we are enabled to destroy by heat coagulation any growth on the surface and in some of the orifices and passages of the body with little fear of either primary or secondary haemorrhage resulting.

The very high voltage obtained from the static machine enables us to excite, with an extremely minute milliamperage, powerful, pervading, and painless muscular contractions capable of breaking down peri- or intra-muscular adhesions. The same high voltage uninterruptedly applied to an insulated patient enables us to stimulate without any unpleasant sensations the skin over the whole body, and this results in, among other effects, an increased secretion of adrenalin from the suprarenal glands and a consequent rise of blood pressure of the greatest value to many exhausted patients.

The fundamental action of high voltage electricity can be best studied by reference to the work of Professor Jellinek, of Vienna.

Professor Jellinek has experimentally shown that it is possible by the employment of lightning or other electrical energy of enormously high potential to drill a circular hole in sheets of glass, stone, wood, metal, or paper, without the edges of such holes showing any trace of heat or chemical action. Conclusions of far-reaching importance and of very wide application may be deduced from the experiments of this distinguished authority.

The theory, however, involved in these experiments is by no means revolutionary, for it merely implies that, providing the blow is sufficiently powerful, the perforating force may function for too short a time to allow of the production of recognizable heat or chemical change. It is thus in some respects analogous to the theory of the action of the clinical high-frequency currents, of which the duration of the current in one direction before its reversal is insufficient to permit the hydrogen ion concentration necessary for nerve or tissue stimulation. It would appear from this theory that the chemical and thermal effects of electricity are preceded by a mechanical action, a stroke or blow. It is very interesting to note how this point has been foreshadowed, as indeed so many of the principles of science have been outlined, by that remarkable Latin poet, Lucretius:

'Again, a blow more severe than its nature can endure prostrates at once any living thing and goes on to stun all the senses of body and mind. For the positions of the first beginnings are broken up and the vital motions entirely stopped, until the matter, disordered by the shock through the whole frame, unties from the body the vital fastening of the soul and scatters it abroad and forces it through all the pores. For what more can we suppose the infliction of a blow can do, than shake from their place and break up the union of the several elements? Often, too, when the blow is inflicted with less violence, the remaining

vital forces are wont to prevail, ay, prevail and still the huge disorders caused by the blow and recall each part into its proper channels and shake off the motion of death now reigning, as it were, paramount in the body, and kindle afresh the almost lost senses.' (2)

In broad outline it is remarkable how vividly this extract illustrates the action of high voltage electricity and radiant energy. Lucretius was not, of course, writing of the action of electricity, since its existence was unknown to him, but of the basic action of nature. A blow more severe than nature can endure, such as a lightning stroke, or a sudden electrical discharge from a source of high potential, can immediately destroy life, 'disordered by the shock throughout the whole frame', but a blow less severe, as from the vibrations of the ether resulting from a high potential discharge, 'kindles afresh the almost lost senses'. For the vibrations of the ether are received as a succession of minute blows.

'If we sit in the sunshine we can realize, if we attend, that we feel all round us a quiver of the ether: it may actually bronze our skins, and on the top of a mountain it may raise blisters. All these skin sensations are due to the ether and its vibrations. The vibrations originated in the sun, and have travelled across ninety-two million miles of empty space, taking eight minutes on the journey before they reach us. They achieve many results on arrival. Photographic chemicals are blackened by the vibrations. Every green leaf elaborates crude sap by their aid, and turns it into feeding material or vegetable tissue.' (3)

The modern view has been well summarized by Professor Bigelow: 'What we observe and measure is always exclusively heat, light, and electricity. These are essentially the same thing, vibrations, only differing in wave length. They may then be considered as one form of energy. We reach an astonishingly simple result. All we observe is energy. All energy is motion.' (4)

The 'ictus' or blow of Lucretius comprises the arrest, absorption, or transformation of this kinetic energy.

As in the case of the plants the absorption of the ultra-violet rays by the tissues achieves many and complex results. The nature of the indirect or consecutive results, such as the formation of vitamins, &c., belongs to the province of the biochemist. But the problem of the action of ultra-violet light is primarily a bio-physical one; for the fundamental principle involved is the disturbance of the electrical equilibrium of the atom by the removal of electrons from one orbit to another or even right out of the atomic system. This disturbance of the electrical equilibrium or 'activation' of the atom occurs when the wave length of the ultra-violet radiation is in resonance with the atomic electrons. The ultra-violet radiation becomes more and more in resonance with the atomic electrons as it becomes shorter in wave length, until a wave length of 2,800 is reached. At this point the absorption band is complete, and remains so until the wave length of long X-rays is reached.

The much shorter wave length of X-rays sets up an electronic disturbance among those atomic electrons that are nearer to the nucleus, and this disturbance in the electrons near to the nucleus is productive of far greater organic chemical effects than are occasioned by the resonant activation of the electrons in the marginal orbits. This appears to be the physical basis for the great difference between the action of ultra-violet radiation and X-rays.

Both the similarity and the contrast between ultra-violet radiation and X-rays are very striking. After both types of radiation there is a latent period, a matter of hours with ultra-violet radiation, and of weeks with X-rays, during which no effects are noticeable. This latent period is followed by an erythema of varying intensity: stimulating in the main in the case of ultra-violet radiation, destructive, except in very mild doses, in the case of X-rays. With ultra-violet radiation it is impossible to produce any harmful results except with a very excessive overdose; with X-rays great care is needed to avoid the production of exceedingly harmful sequelae. Therefore it

has been reasonably inferred 'that the organic chemical changes and the resulting chemical effects depend profoundly on whether the electronic disturbance in the atom is nearer to or further from the nucleus'.

It appears that, in the tissues, ultra-violet radiation is primarily absorbed by the chromatin of the cell nuclei, and this is most in evidence when the cells are undergoing mitosis. And it is the increased radio-sensibility that occurs in cells when they are multiplying by the division of their nuclei (mitosis) that confers upon radiotherapy a so-called selective action on such tissues as neoplasms, the cells of which are in a far more frequent state of division than the cells of more stable structures such as bones or muscles. It thus comes about that, by the action of X-rays, we are able to diminish the action of over-active glands; or, by a more intensive use of the X-rays, we can entirely destroy their cells. It is also by such action that the resolution of fibrous tissue or the destruction of cancer cells can be brought about.

The electrotherapist is sometimes criticized because he concerns himself with such a large number of diseases. There is a type of medical man who would tolerate an electrotherapist who confined his activities to one or two diseases, but cannot understand how he can even profess to benefit such a large number of entirely different conditions. Such a man fails to realize the fundamental principle that electricity is not a specific for any one type of disease, but that it is capable of affording the means for benefiting a very wide range of conditions.

It is important, moreover, to realize that electrotherapy is not antagonistic to any other form of treatment; it needs the association of the bacteriologist and serum therapist, it can be usefully associated with rational drug therapy, it is an adjuvant rather than an antagonist to the surgeon, it is indispensable to the dermatologist, and most helpful to the gynaecologist.

Penetrating, as electricity does, into so many and varied branches of the medical profession, there is no training so

essential to the electrotherapist as the diversified medical experience to be gained by no other means than by general practice. Specialists in some other branches of medicine may be able to dispense with such experience; but the specialist in electrotherapy who bases his work upon a knowledge of electricity rather than upon a knowledge of general medicine, will inevitably tend to become an electrician practising medicine, rather than, as unquestionably he should be, a medical man utilizing electricity to achieve a certain desired effect.

The successful administration of medical electricity demands a sound all-round knowledge of general medicine, combined with a knowledge of the action and mode of application of the various electrical methods; and of these two the former is infinitely the more important and more difficult to acquire.

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## CHAPTER II

## THE THERAPEUTIC ACTION OF THE CONSTANT CURRENT

THE therapeutic effects of the galvanic current vary with its method of application. If the current is interrupted, reversed, or suddenly varied in intensity, muscular contractions are excited and influence its action. When the current is continuous and maintains a permanent value between make and break (the constant current), its action at the electrodes is not of the same nature as in the interpolar path through the tissues: for at the electrodes electrolytic effects are manifested, and these result in tissue destruction, both by electrical decomposition and by the chemical action of the electrolytic products.

The action of the constant current upon living tissues is a very complex one, and will be best understood after a study of its physical action.

If we take a rectangular vessel A, divided into two compartments C and D by a membranous partition B, and fill these two compartments with a solution of uniform concentration and character, the osmotic pressure (namely, the force exciting diffusion of the fluids through the membrane) is at zero; and the fluids are, as it is termed, isotonic. But if the molecular concentration of the solution in D is greater than that of the solution in C, the osmotic pressure of the solution in D is said to be hyper-tonic, and that in C hypo-tonic. In other words, the osmotic pressure of a solution is directly proportional to its concentration in unit volume. Certain substances, such as the salts, when dissolved in water, exercise an osmotic pressure greater than can be explained by their molecular concentration. Therefore it is suggested that the molecules have been divided into smaller particles or sub-molecules. Substances which give in water-solution this increased osmotic pressure are found to conduct the electrical current, and their molecules are at the two poles split up or decomposed by

the passage of the current. These substances include the acids, bases, and salts. They are termed electrolytes, or ionogens, and the smaller substances into which they are split up are called 'ions' or travellers, a name first conferred upon them by Faraday, and derived from the Greek word *ἰόν*.

Substances such as alcohol, sugar, chloroform, whose solutions give a normal osmotic pressure and do not conduct the electrical current, are termed 'non-electrolytes'.

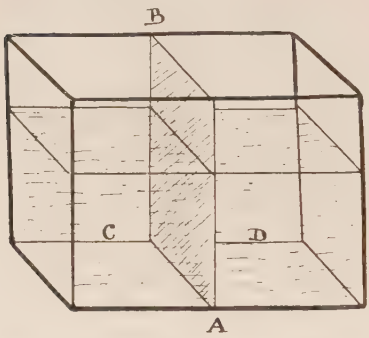


FIG. 2. Rectangular vessel divided by membranous partition to illustrate osmosis and formation of ions.

When a salt, such as sodium chloride, is dissolved in water, it is split up or dissociated, *without the application of any external force*, into a positively charged sodium ion and a negatively charged chlorine ion. On the application of an electrical current, the positively charged sodium ion is attracted towards, and carries its electrical charge *down* to, the negative pole, and is hence called a *kation*. The negatively charged chlorine ion is attracted by the positive pole, and hence carries its charge *up* to the positive pole, and is called an *anion*. The current is hence a double one.

This process of the dissociation of salts or other 'ionogens' into ions is termed 'ionization'. This term 'ionization' is used in electrotherapy in a very confusing and faulty manner; it is frequently employed to designate a form of treatment which has no relation whatever to the correct application of the term. Let us clearly understand what is correctly implied by the term.

The term ionization, when applied to a liquid, implies the dissociation of a substance into ions without the appli-

cation of any external force, as is the case when a salt is dissolved in water. The term ionization, when applied to gases, implies the splitting up of the molecules of the gas or air into ions, by the application of an external force, such as X-rays or ultra-violet light: the gas, or air, is, by means of this external force, rendered a conductor of electricity in the same way as water is so converted by the dissociation of a salt into ions, the action of the X-rays on the air or gas resulting in the formation of both positive and negative ions.

The kations consist of the metals and hydrogen. The anions include iodine, chlorine, the bases, and acid radicles, such as hydroxyl, OH.

It is the ions which convey the current through the electrolyte; the anions carrying a negative charge to the positive pole, and the kations carrying a positive charge to the negative pole. In the words of Leduc, the movement of the ions in the electrolyte 'est le courant électrique lui-même'. The dissociated molecules, whilst they are in the ionic state, do not exhibit their former chemical affinities.

The electrical charge of the ion, according to Nernst, momentarily replaces the affinity of the atom. When the atom or radicle has lost this charge, its affinity reappears (Nogier).[1] (1)

Apart from variations due to temperature and E.M.F., ions have a specific rate of movement according to their nature. The resistance, and conversely the conductivity, of electrolytic solutions is determined by the number of ions they contain, and by the rate of movement of those ions.

The velocity of the different ions is partly in relation to their atomic weight, and is partly due to their hydration, namely, the number of molecules of water that they attract to themselves. (2)

[1] It would, perhaps, be more explicit to say that the chemical affinity of an atom in an ionic state is temporarily inhibited by the electrostatic attraction of a neighbouring and oppositely charged ion.—W. J. T.

The conductivity of the following ions is taken from the tables of Kohlrausch and Holborn:

*Kations*: Potassium 65·3. Sodium 44·4. Lithium 35·5. Hydrogen 318.

*Anions*: Chlorine 65·0. Iodine 66·7. $H_2SO_4$ 66·7. Hydroxyl 174.

It will be noticed that among the kations the hydrogen ion, and among the anions the hydroxyl ion, is by far the fastest. It will be also seen that the lithium ion, which has an atomic weight of only seven, travels at little more than half the rate of the potassium ion, which has an atomic weight of thirty-nine. The low velocity of the lithium ion is due to its hydration, namely, the large number of molecules of water which are attached to it.

These ions, which are present in millions in electrolytic solutions, have, on account of the resistance they encounter and their frequent collision with the undissociated molecules in the solution, a very slow rate of travel.

The ionic velocity in an electrolyte varies directly with the E.M.F. The larger the surface of the electrodes, the greater the number of ions which will be included in the interpolar path, and hence the greater the amount of current which will be carried with a constant E.M.F. In an electrolyte of one square centimetre cross-section, with a fall of potential (Potential Gradient) of one volt per centimetre length, the hydrogen ion has been found to move only at the rate of 0·0033 cm. per second, and the potassium ion at 0·00067 cm. per second.

According to Kohlrausch's *Law of the Independent Migration of Ions*, the conductivity of an electrolyte, containing a variety of ions with varying velocities, is the sum of the velocities of the individual ions.

One of the most striking, and, from the electrotherapeutic standpoint, one of the most important characteristics of the passage of a galvanic current through an electrolyte, is the absence of any chemical action in the general bulk of the electrolyte as the result of the passage of the ions; it is only when the ions reach the electrodes

and there surrender their electrical charges that they regain their chemical affinities and exercise their specific reactions. The following experiment of Hittorf illustrates this: Take a rectangular glass jar, divided by means of two porous plates into three divisions. Having filled each of the compartments with a solution of copper sulphate, place in each of the outer divisions a copper electrode, and

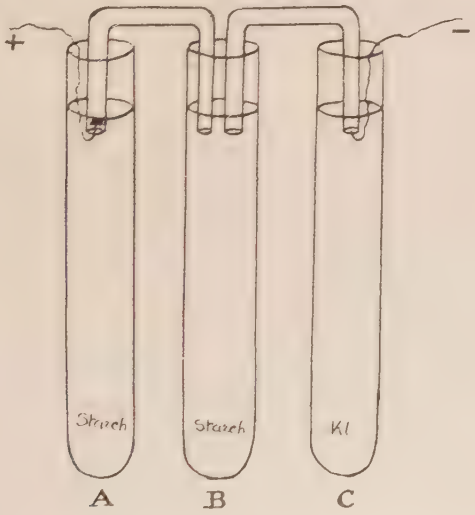


FIG. 3. Author's experiment to illustrate transport of ions.

connect one of these with the positive, and the other with the negative terminal of an electrical supply. After a strong current of several amperes has passed for some minutes, the solution in the anodal compartment will be found to have become stronger, in the cathodal compartment the solution will be weaker, and in the centre compartment the solution will be found to be unaltered in strength. The same result may perhaps be more readily shown by the following simple experiment of the author (Fig. 3). Take three glass test-tubes, A, B, and C. Fill C with a 2 per cent. solution of potassium iodide, and A and B with a weak emulsion of starch. Connect the tubes A, B,

and C with narrow strips of coagulated egg albumen, obtained from the white of a hard-boiled egg. In the tube C place the negative electrode of copper, zinc, or other metal; and in the tube A place the positive electrode of platinum wire in contact with the strip of albumen submerged in the starch emulsion. Pass a galvanic current of about 5 ma. for about forty-five minutes. The contents of the tubes B and C will then be found to be unaltered, but in immediate contact with the positive electrode there will be found an intense blue discoloration due to the starch iodine reaction.

This experiment therefore shows that the very delicate starch iodine test fails to reveal the presence of any free iodine except in contact with the positive electrode, where the iodine ion, having passed through the tube B without producing any chemical change in its path, loses its negative electrical charge to the positive pole, and regains its chemical affinity as an iodine atom.

The chief value of these experiments and of the somewhat similar experiments of Chatsky, described below, lies in the evidence they afford of the fallacy of the deep ionic medication theory, which is so widely held and taught.

According to this theory it is held that by means of the electrical current it is possible to introduce drugs into the deeper tissues of the body and there obtain the specific action of the medicament.

The first of Chatsky's experiments is so simple that every electrotherapist should perform it for his own instruction.

Fig. 4. A hole is scooped in a potato at A, and filled with a 1 per cent. solution of potassium iodide; platinum wire electrodes are inserted into the potato, the positive at B and the negative at C. A continuous current of about 3 ma. is passed for about thirty minutes. Then, on bisecting the potato longitudinally through the points of insertion of the electrodes, a short pencil-like rod, clearly and sharply defined, of an intense blue colour, due to the action of the liberated iodine on the starch of the potato, will be seen starting from the positive electrode and

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directed towards the hole A. After a short time the pencil-like rod, owing to diffusion, merges into a wider and less sharply defined area. Between the upper extremity of this rod and the hole A, no colorization and no change in the substance of the potato can be detected. Incidentally two

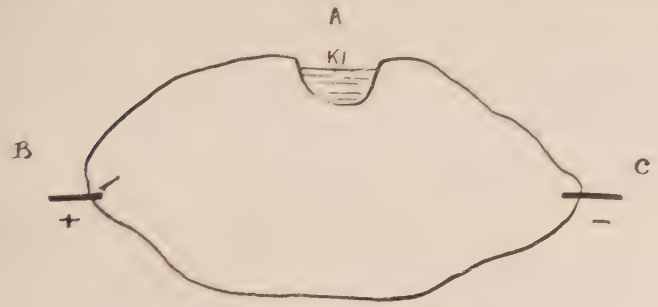


FIG. 4. Chatsky's first experiment.

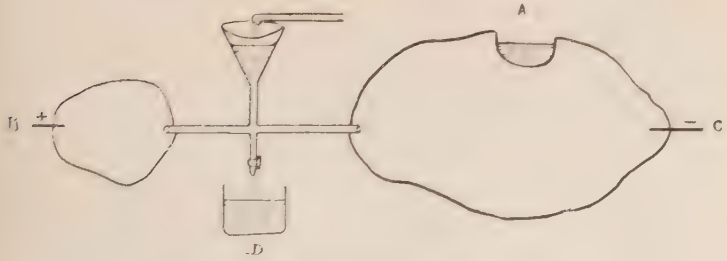


FIG. 5. Chatsky's second experiment.

other points may be noted from this experiment: (1) the diffusion of the lines of force, and (2) that fresh ions may start from any part of the interpolar path and share in the conveyance of the current.

In Chatsky's second experiment, two potatoes are connected by a cross-shaped glass tube, through which a continuous stream of sodium chloride solution flows in a transverse direction to the current; see Fig. 5. A solution of potassium iodide is inserted in the hole A, and an electrical current passed, as in the first experiment; but in this

case no blue coloration appears at the positive pole, but a slight blue colour, due to the starch iodine reaction, can be detected in the vessel D.

This experiment is in full accord with the phenomenon attending the so-called ionization with strychnine in Leduc's experiments with rabbits.

Fig. 6. In this experiment, two rabbits, A and B, are taken, and, their sides having been shaved, a pad soaked in a 2 per cent. solution of strychnine is applied to one shaven side of each rabbit, and to the other side a pad soaked in a 2 per cent. solution of sodium chloride is applied. The rabbits are connected up in series with a

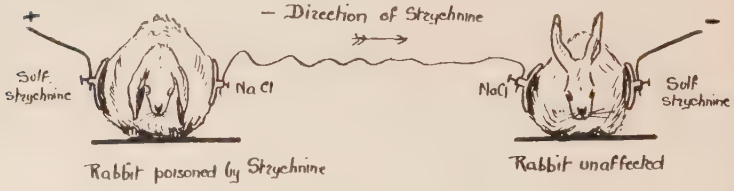


FIG. 6. Leduc's experiment.

galvanic supply, and the electrodes are so arranged that the strychnine pad is under the positive pole in the rabbit A and under the negative pole in rabbit B. A current of 50 to 100 ma. is applied for some minutes, with the result that the rabbit A dies in convulsions, whilst the rabbit B is unaffected; unless, perchance, the current is reversed, when rabbit A survives and rabbit B succumbs.

The sequence of events is quite clear in this case; the strychnine, being an alkaloid, is a kation, and serves to conduct the current through the badly-conducting skin under the positive pole. Having been carried to the subcutaneous tissues by the strychnine ions, the current is then carried by the hydrogen and other ions in the tissues, and the strychnine atoms are swept away in the blood stream (in the same way as the iodine atoms are carried to the vessel by the transverse sodium chloride stream in Chatsky's second experiment) and carried in the

course of the circulation to the spinal cord, where they exercise their lethal action.

In a similar manner the presence of iodine and other drugs in the urine may be accounted for when introduced to the subcutaneous tissues during attempts at ionic medication.

It is not necessary, however, to rely upon these experiments, for the most direct proof against the practicability of deep ionic medication is to be found in the failure to detect the presence of the drug deeper than the superficial layers of the skin. The experiments of Tuffier and Maute failed to detect the presence of salicylate beyond the superficial layers of the skin.

Dr. Levick, Electrotherapist to the Shepherd's Bush Orthopaedic Hospital, has very kindly sent me the following particulars of a most careful and instructive experiment which he performed confirming the work of the French investigators:

'A patient suffering from sciatic nerve degeneration, complicated by ischaemia of the foot, was about to undergo amputation of his leg. He allowed me to perform the following experiment. Two ionization pads, each consisting of sixteen layers of lint, were bandaged to his foot, one on the dorsum, the other on the sole. The pad applied to the dorsum was soaked with a 2 per cent. solution of sodium salicylate. The pad applied to the sole was soaked with tap water. The usual precautions were taken to prevent short-circuiting between the two pads. Metal gauze electrodes connected the pads with the galvanic current regulated by a shunt resistance. The pad containing the sodium salicylate was made the negative, and a current varying from 60 to 70 ma. was run through for three-quarters of an hour. An hour and a half later the patient was taken to the operating theatre and his leg was amputated.

'Dr. Mellanby, of St. Thomas's Hospital, had kindly consented to carry out the tests for me. I thought that for the experiment to be of any real value, a pharmacist

of unquestionable authority must do these. I sent the amputated limb straight to him. He made extracts of the tissues of the foot from several places at varying depths, from the superficial fascia down to the tarsal joints. He assured me that he had employed very delicate tests which would have shown the slightest presence of salicylic acid, but that they were absolutely negative. The significance of this experiment was enhanced by the fact that the circulation was extremely sluggish, and had any appreciable quantity of salicylic acid been conveyed into the tissues there was less chance than usual of its being carried away.'

The result obtained in the above experiment is fully confirmed by the work of Dr. Inchley on 'The Influence of the Electric Current on Absorption of Drugs'. (3) Dr. Inchley experimented on the electrical absorption of atropine, strychnine, calcium, iron, copper, the cyanides, and salicylates. He gives the following summary of his conclusions:

'1. Both positive and negative ions can be made to be absorbed through the skin or mucous membrane by means of the electric current if solutions of the drug are applied at the appropriate electrode.

'2. The current is conveyed through the body by the tissue ions; after the introduction into the body of the foreign ion the current has no further appreciable influence upon it. With a current localized in the tongue the atropine ion rapidly reaches the heart. The ferricyanide ion penetrates through the skin but after this the electric current has no further influence.'

In reference to the amount of salicylates which can be electrically forced through the skin, Dr. Inchley found that the amount of salicylate excreted by the urine of cats treated for half an hour with a current of 25 ma. with a pad 20 square centimetres moistened with a solution of sodium salicylate, was under a milligram.

Even if such drugs as salicylic acid and lithium were capable of being conveyed to the deeper tissues by the electrical current, there is no reason to suppose that they

would necessarily exercise any beneficial effect in those regions. On the contrary, in general therapy we give such drugs, in large quantities, and in oft-repeated doses, with a view to some neutralizing action on the blood in certain diseases, and no special benefit is alleged to follow from their direct injection to the diseased locality. Again, where a drug, such as cocaine, can be electrically introduced to the sensory nerve endings, its action has been found to be uncertain, and by no means so satisfactory as when injected hypodermically.

The slow rate of movement of the ions is another point which seems to be overlooked by the holders of the ionic medication theory, and yet this fact alone is sufficient to disprove many of the claims made for this theory.

The evidence against the possibility of the local medication of the deeper tissues by drugs, electrically introduced, is so overwhelming that it is extraordinary that this theory of ionic medication should be so widely held. And yet it is only a case of history repeating itself, for very similar theories were advanced by Privati, in 1747, and by Sir Benjamin Ward Richardson, in 1858. Nevertheless, however fallacious this theory of ionic medication may be, it must be admitted that its revival in the twentieth century has been of the greatest value to the development of electrotherapy. Many persons, both patients and medical men, with little or no knowledge of electricity, but inspired with that marvellous faith which a bottle of medicine, of unknown action and of uncertain composition, invariably imparts, were irresistibly attracted by a theory, according to which, as Priestley says, 'medicines might be made to operate without being taken into the stomach'. Moreover, as the result of this theory, we have learnt the proper manner in which to administer the galvanic current. Instead of, as formerly, administering the current with small electrodes over small areas for a few minutes, we, as the outcome of this theory, now apply the treatment over large areas, with currents of low density and high intensity, for thirty, forty-five minutes, or 'as long as the

time of the department will permit', for periods of weeks or months.

We have seen that the conductivity of an electrolyte depends upon the number of ions it contains, and upon the velocity of those ions. Once within the skin the situation is governed by the relative velocity of the hydrogen kations and the hydroxyl anions to the other ions present in the tissues. So far as I am aware even an approximate calculation of the hydrogen and hydroxyl ions available within the tissues for the transmission of the electrical current cannot be made; but upon any estimation they must so enormously outnumber those ions introduced from outside, as to render the latter an utterly negligible quantity in considering the transmission of the current through the tissues. This question of the transmission of the current through the tissues is governed by Kirchhoff's law of branched circuits. Why should we abrogate the established laws of electricity to bolster up this theory of ionic medication?

Will any upholder of that theory explain why the current travels, as becomes necessary if the theory is correct, by the comparatively high resistance offered by the ions of the drugs introduced, in preference to the path of far lower resistance afforded by the hydrogen and hydroxyl ions present in the tissues in far larger numbers and of far higher velocity?

The arguments against the theory of ionic medication may be briefly summarized as follows:

1. While an ion is sharing in the convection of the current its chemical affinity is temporarily inhibited by its electrical charge, therefore as an ion it can have no therapeutic action.

2. The very low velocity of the ions employed in medical treatments of this character and the very low potential at which they are applied entirely preclude the deep penetration claimed for them during the brief period allotted to an electrical treatment.

3. Such drugs as salicylic acid, commonly employed,

need to be present in the tissues in considerable quantities in order to exercise their therapeutic effect, and it is difficult to conceive that such drugs in the infinitesimal quantities, which could possibly be introduced by ionic medication, could have any beneficial action.

4. Many workers of extensive experience have failed to detect any difference in their results, provided the current is administered at a similar intensity, and for a similar length of time, whatever salts or drugs are employed to moisten the pads.

5. Very careful experiments conducted both in this country and in France, by experienced electrotherapists in collaboration with skilled chemists, have failed to detect the presence of the drug, after its attempted introduction by electrical means, deeper than the superficial layers of the skin.

The experiments to prove the electrical introduction of the ferricyanide ions into the knee joint of the monkey should be entirely disregarded, since after the ferricyanide ions had been electrically introduced into the neighbouring superficial layers of the skin, the knee joint of the dead monkey, so treated, was allowed to soak in the reagent for more than twenty-four hours, thus admitting a very simple explanation of the phenomenon obtained, namely, by the diffusion that we should expect to occur under such conditions.

As regards the alleged introduction of radium salts deeply into the tissues, the marvellously delicate tests available for the detection of radium, even when present in inconceivably small quantities, renders the use of these salts very misleading for the purpose of demonstrating by analogy the introduction of other drugs deeply into the tissues in chemically active quantities.

It is true that drugs, electrically introduced in an ionic state into the superficial layers of the skin, may be from thence absorbed into the general circulation, and may then exercise their specific action on the system generally.

In view of the extremely minute quantities which can

be so introduced and the complicated technique of the method, there is nothing to recommend its adoption in preference to inunction or oral administration. Take, for instance, cocaine, a drug whose nature readily admits of its electrical introduction to the sphere of its therapeutic action; its effects, when electrically introduced to the subcutaneous nerve endings, have not been found to be by any means so satisfactory or reliable as when it is hypodermically injected.

A theory has been put forward that electrically introduced drugs are more slowly excreted than those taken by the mouth, and that, owing to their delayed action, better therapeutic effects are obtained. Bourguignon found, when experimenting on the amount of iodine introduced and eliminated during ionization, that the elimination of the electrically introduced iodine persisted in the urine for four or five days after the cessation of the seances. From this delay in excretion Bourguignon argues that a reserve of iodine accumulates in the thyroid, and that in this way the thyroid gland plays an analogous part from the point of view of the electrically introduced iodine to that which the liver plays in the storage of sugar. Bourguignon further claims that: 'The slower elimination of iodine when introduced by electrolysis, than when introduced by the mouth, shows that with this method iodine is better incorporated with the organism. At the same time an explanation is afforded of the prolongation of improvement during the intervals of treatment.' (4) Unfortunately, although these experiments to show the slow elimination of electrically introduced iodides were most carefully performed, no control experiments were performed to show the period of elimination when iodides are taken by the mouth. Reference to pharmacological literature, however, shows that iodides are in part slowly excreted when taken by the mouth. Most of a single dose is eliminated in a few hours, but the remainder is excreted very slowly. With a dose of seven to fifteen grains the iodine reaction persists in the urine for forty

hours, after larger doses or continued administration traces persist for twenty days. With a single dose of fifteen grains administered to a man, 80 per cent. was excreted in twenty-four hours, and 20 per cent. between twenty-four and forty-eight hours. Iodized fats, given by the mouth, are eliminated even more slowly, so that, even if the theory of the slower elimination of the electrically introduced iodides were proved, which in the absence of control experiments is certainly not the case, nothing would be gained by the use of electricity, for a still slower excretion can be obtained by the more simple procedure of administering iodized fats by the mouth.

When the above points are rationally and dispassionately considered, it must be admitted that the theory of ionic medication fails on theoretical, on practical, and on experimental grounds.

The claim put forward by some electrotherapists that the galvanic current exercises an electrolytic action throughout the whole of its interpolar path need not be seriously considered: such a theory is of course entirely opposed to the fact demonstrated many years ago by Faraday, that electrolytic action takes place solely at the electrodes. When at a loss to explain the action of the galvanic current some electrotherapists glibly talk of the 'ionic interchange which takes place within the tissues as the result of the action of the galvanic current'; but what the nature of this 'ionic interchange' is, or how it acts, they do not attempt to explain.

The conclusion arrived at then is that the function of the solution of salts, or of other drugs with which the pads are moistened, is to supply the ions necessary for the transmission of the current through the superficial layers of the skin, an area which is normally very deficient in ions. Without the employment of such solutions the electrical resistance of the skin would be so great that a very high voltage would be necessary to force the necessary current through it: burns of the skin would consequently result, and the administration of the treatment would be ex-

tremely painful. When the deeper layers of the skin are reached, the fluids in which the tissues are bathed contain vast numbers of the relatively fast hydrogen kations and the hydroxyl anions, and hence these serve to carry, at any rate, by far the greater amount of the current.

An attempt is sometimes made to explain the action of the galvanic current by the electrotonus which it excites in the nerves through or along which it passes. It will be remembered that electrotonus is the condition produced in a nerve by the passage of the constant current. If the constant current is applied through the nerve of a nerve-muscle preparation in the same direction as the natural nerve currents, the excitability of the nerve is increased (katelectrotonus); but if it is applied in a direction contrary to the natural nerve currents, the excitability of the nerve is diminished (anelectrotonus). This is very similar to what occurs with the Watteville currents, katelectrotonus corresponding to the Watteville current in tension, and anelectrotonus to the Watteville current in opposition. Relying on this laboratory experiment it is claimed that the constant current applied with the negative pole at the proximal end of the nerve or limb has a sedative action, and with the poles reversed an exciting or irritating action. No definite conclusions can, however, be drawn from a laboratory experiment in which the whole of a current of a definite and known intensity is passed along an isolated nerve, in regard to the effects arising from the passage of an extremely minute current of unascertainable strength along a nerve of high electrical resistance situated deeply in tissues of very low electrical resistance.

Personally I have never been able to convince myself that I have derived any advantage from such an arrangement of the electrodes, and in any case the benefit resulting from such a cause would be of very brief duration. In practice I find it better to arrange my electrodes so that the more stimulating skin effects are felt by the patient in the neighbourhood of the seat of greatest pain, thus obtaining a counter-irritating effect, and at the same time

satisfying the patient, who seldom appears happy unless he or she feels 'something going on' near the seat of the pain.

To what, then, are the benefits due which undoubtedly result from a prolonged passage of a strong continuous current through the tissues?

In order to answer this question satisfactorily the theory adopted should show:

1. That the electrical current produces a certain effect.

2. That this effect is such as is likely to result in benefit in those cases for which an improvement from a prolonged administration of a strong galvanic current is claimed.

3. That the prolonged administration of a continuous current is followed by such an improvement in the affected part as would be expected from the alleged action of the continuous current.

The beneficial effects, resulting from the passage of a continuous current through the tissues of the human body, are partly due to the heat generated in the tissues by the passage of the current, and the increased temperature in the affected part which results from this heating effect.

1. That an appreciable increase of temperature would be generated in a limb by the passage along it of a current of 100 milliamperes for thirty or forty minutes would be foretold by any physicist. That such an increase of temperature does actually occur can be confirmed by any electrotherapist when treating a case of sciatica by a continuous current of high intensity (longitudinally) applied along the length of the limb; for if he applies the palm of his hand to the knee of the treated side he will find that it is perceptibly warmer than the knee on the other side.

In order to obtain objective, in place of subjective, evidence on this point, I have performed the following clinical experiments.

My method for the treatment of sciatica by the continuous current often consists in applying the negative pad, about $7 \times 5$ inches, to the sacro-iliac articulation on the affected side, and a positive pad round the foot, ankle, and lower third of the leg. The pads are soaked with a

weak solution of sodium chloride, and a current as strong as the patient will tolerate is passed for forty minutes.

A current strength of from 80 to 110 ma. is often reached by the end of the treatment.

In order to find the increase in the skin temperature resulting from this method, I secured a surface thermometer to the thigh, by means of a rubber strap, a quarter of an inch above and to the outer side of the patella. The thermometer, so placed, was nine inches above the upper limit of the pad on the leg: the rise in temperature was consequently due to an increase of heat in the whole limb, and not to a local rise under the pad due to the high skin resistance at the point of application of the current.

As the result of several experiments of this kind, I find that the skin temperature in these cases usually rises from 2° to 4° F., varying with the intensity of the current and the duration of the treatment.

The following is a typical case:

Mrs. G. Sciatica of right leg. Pads arranged, and treatment administered by continuous current as above described.

| *Time in minutes.* | *Temperature of affected leg.* | *Milliamperes.* |
|---|---|---|
| 0 | Thermometer shaken to zero | 0 |
| 5 | | |
| 10 | 89° F. | 20 |
| 15 | 90 | 30 |
| 20 | 91 | 50 |
| 25 | 91·6 | 60 |
| 30 | 91·8 | 70 |
| 35 | 92 | 80 |

The diathermy current in this case was then applied with the following result:

| | | |
|---|---|---|
| 5 | 94·2 | 700 |
| 10 | 98·4 | 900 |

The following control experiment was taken on the sound leg:

| | |
|---|---|
| 0 | Zero |
| 5 | 91° F. |
| 10 | 91 |
| 15 | 91 |

The control on the sound side shows that the thermometer employed took five minutes to reach its correct reading. In taking the temperature in cases of sciatica I have frequently found that the skin temperature on the affected side is often 2° F. lower than on the sound side.

I found that the resistance of a man's leg with the pads arranged in the way described was at the end of a treatment 500 ohms.

The equation, in accordance with Joule's law: $I^2RT \times 0{\cdot}24$ would be $0{\cdot}1^2 \times 500$ ohms $\times 2400$ sec. $\times 0{\cdot}24 = 2{,}880$ calories. Thus a considerable amount of heat is generated in a leg treated in this manner for forty minutes (2,400 seconds) with a current of 100 ma. This amount is, however, in excess of the amount usually obtained, as the current intensity of 100 ma. is not reached in the early part of the treatment.

2. How does this theory of the increased production of heat in the deeper structures and through the entire length of a limb or part of the body explain the beneficial effects of this form of treatment and indicate its adoption in, for instance, that vast field of medicine included under the modern title of 'fibrositis'?

Let us accept the theory that this condition is due to a toxaemia caused by some bacterial infection, though the bacteriologists are by no means agreed, either in regard to the type of bacteria, or to the method of infection.

Now most medical men will admit that this form of toxaemia becomes active and produces the symptoms characteristic of fibrositis when the vitality of the patient or the part affected becomes lowered, either by strain, accident, worry, damp, over-fatigue, or other exhausting cause. It will, moreover, generally be found that the affected part in chronic cases is colder and has a feebler circulation than normal, and it is a matter of common knowledge that fibrositis becomes more common as the resisting powers of the patient diminish with advancing years.

As Hanot puts it, 'Tout ce qui affaiblit prédispose'.

I claim that the continuous current by raising the temperature of the limb or part of the body, in the way I have indicated, and by the increased blood supply, which results from the increase of temperature, follows the lines of treatment indicated by the conditions mentioned. Moreover, I claim that the increased vitality and nutrition of the tissues, thus excited, tend both to cure the disease and to guard against its recurrence.

3. To illustrate the effects of prolonged treatment by the continuous current, let us take the case of rheumatoid arthritis of the knee joint. This joint lends itself better than any other to the concentrated action of intensive galvanism, and, in my experience, yields better results from electrical treatment than any other joint. Such a joint before treatment is swollen, thickened, painful, tender, fixed, or limited in its range of movement; the skin is glossy and denuded of hair, and the patient is unable to walk. After a period of treatment, varying from a fortnight to six months, according to the severity and duration of the complaint, the pain has ceased, the thickening has decreased, and the joint is far less swollen, it is more free, and in some cases has fully regained its mobility; the skin has regained its normal texture, there is, perhaps, even an overgrowth of hair on the part; and finally the patient is able to walk.

Such are the results, I submit, that we should expect from the increased blood supply resulting from the application of the galvanic current. If the resulting reduction in swelling and thickening were due to an electrolytic action, we should reasonably expect, at any rate, a temporary increase of pain and inflammation. On the contrary, we find that one of the first benefits obtained is a decrease of pain, and this may be explained by the relaxation of tension resulting from the increase of the temperature of the joint.

We thus see that a considerable increase in temperature results in a limb treated by intensive galvanism. Such an increase in temperature leads to an increased blood supply.

The beneficial results produced are such as would be expected from increased nutrition and increased cellular activity consequent upon an increase in the blood supply of the affected part.

It may be urged that if the generation of heat within the tissues is so beneficial, it would be better to utilize the more powerful heat-producing action of the diathermy current. But it does not necessarily follow that because a method of raising the heat of a part to its normal, or even slightly above its normal temperature, is beneficial, that therefore it is advisable in all cases to raise its temperature to fever heat. Practical experience shows that the two currents, the continuous galvanic and the oscillating diathermic currents, have each their sphere of action. In old-standing chronic conditions, where the local circulation and nutrition need improvement, the best results are obtained from the galvanic current. But acutely painful conditions, especially those attended with spasm, yield most readily and quickly to the more intense heat of diathermy, which speedily relaxes the spasm and hence relieves the pain. It is often better to produce a gentle action for a prolonged period than an intensive action for a short time. When I have applied weak diathermy currents, not exceeding 300 ma., for thirty or forty minutes longitudinally through the limb in sciatica, I have found little difference in the results obtained from those yielded by the constant current for a similar period. Perhaps the best results are obtained by administering a diathermy current of moderate strength for about ten minutes, until the limb feels perceptibly warm to the touch, then continuing the treatment with intensive galvanism for a further period of thirty or forty minutes. When I have treated the sciatic limb for about ten minutes with a strong diathermic current of from 700 to 900 ma. the results have not been by any means so good.

But does the continuous current in its interpolar course between the electrodes produce no other effects beyond those of heat? Has the bombardment of the cell consti-

tuents by millions of ions, with a force capable in the aggregate of producing an appreciable degree of heat, no stimulating effect on the activity of the cells themselves? It seems reasonable to suppose that this 'ionic massage' must have some such effect. It is a difficult matter to prove, and I would prefer to base the therapeutic claims of the galvanic current upon the surer and more evident basis of heat production. In this connexion Professor Soddy propounds an interesting question in his book (5), *Matter and Energy*: 'Have the minute cells of the body the power of taking advantage of the difference in the temperature of the molecules bombarding them, and when one comes along at more than the average speed, absorbing it and its energy, building up a larger cell thereby, which in course of time undergoes metabolism and evolves again its store of energy?' This is, as Professor Soddy states, a fascinating and legitimate line of inquiry, but it is an enigma of which I will not attempt to offer a solution.

Hitherto we have mainly discussed the interpolar action of the galvanic current: but there is little doubt that its polar action is the more important therapeutic factor, and it is probably due to the more lasting effects of the products of this polar action that this form of treatment is of more benefit in certain chronic conditions than diathermy, the action of which ceases with the termination of its application.

The polar effects on the patient's skin will depend upon the nature of the solution with which the pads are moistened. If solutions of zinc or copper are employed, oxychlorides of these metals will be formed in the neighbourhood of the positive pole, and these products will quickly cause a burn of the skin. If, on the other hand, solutions of sodium salicylate or sodium chloride are employed, merely a stimulation of the cutaneous nerve endings will result in place of the caustic action. Such an action is usually termed counter-irritation, but reflex stimulation would perhaps be a better term.

Counter-irritation is a very old therapeutic method, and

it is interesting to find how closely the older views of its action correspond with the modern view outlined by Dr. Sonntag (see Chapter I).

Dr. Mitchell Bruce in his *Materia Medica and Therapeutics*, 1885, concludes in reference to the theory of the action of counter-irritation:

'1. That rubefacients and vesicants will afford relief to the circulation of parts in immediate vascular connection with the selected area, by attracting blood and draining off plasma; to the same extent the general circulation will be depressed, and visceral congestion or inflammation will be diminished. At the same time the heart will be relieved.

'2. That the irritation of the cutaneous nerves will modify in a simple reflex way, through the centres in the brain and cord, the circulation and nutrition generally of the parts beneath; the impression which passes in being immediately reflected along the vascular or trophic nerves.

'3. That possibly the irritation of the local nerves and vessels may affect the trophic centres in the brain and cord, presiding over the area of the skin; and that this disturbance may so influence a neighbouring trophic centre (say of a joint) as to produce through it a change in the nutrition of the tissues (such as a joint) in the neighbourhood of the area to which the irritant was applied.'

This last conclusion is in accordance with the reflexes of Löven (1866). Löven showed that by stimulating the central end of the sensory nerve of the rabbit's ear, a vasodilatation occurs in the ear, accompanied by a vasoconstriction effect in the other parts of the body. An increased blood supply is consequently induced in the ear, both by the local vasodilatation and the general vasoconstriction. A similar effect was obtained when a like experiment was performed on the knee joint.

It is true that a somewhat similar result to that which we obtain from reflex stimulation by the constant current may be obtained from merely painting on an irritating application, such as the tincture of iodine. Lauder Brunton quotes such a result in his book, *The Action of Medicines*,

1895. 'Some years ago, I saw a very striking example of this (counter-irritation) in the casualty department. A workman came with his hand quite swollen and stiff. He was unable to work at all because the fingers were so stiff, he could not close his hand, and it was at the same time painful. I painted the back of the hand with iodine. It did not do any good, and he went on for two or three weeks without any improvement. At last I said to him, "You must paint more on". The next time he came he had been painting very vigorously indeed. The hand was swelled up to twice its normal size, and I said, "You have overdone it now"; but he had not overdone it. He had just done the right thing, and, a few days afterwards, the blebs of the blisters had disappeared, and with them the whole of the swelling and to a great extent the stiffness also, so that the man was able to go back to work quite comfortably. I think very frequently we do not get the improvement we ought to from counter-irritation from not applying it sufficiently strongly.'

It may be asked, Why should we have recourse to the complicated processes of electricity if effects, so similar to those obtained from the constant current, can be secured merely by painting on tincture of iodine? Apart from the fact that with the electrical method it is not necessary to cause the hand to swell to twice its natural size, the reflex stimulation set up by the current is directly under the control of the operator during the whole of its application, and can be suitably regulated according to the toleration of the patient. And, by as much as the electro-deposition and 'electro-incorporation' of a caustic solution of the oxychloride of zinc is infinitely more effective than the mere painting on of a similar solution: in a like manner and to a similar degree, the direct stimulation of the subcutaneous tissues and nerve endings by a counter-irritant, electrically introduced, and generated in a nascent state, is incomparably more effective than the counter-irritation obtained from merely painting a tincture on the skin, rubbing in a liniment, or applying a blister. Moreover, the

thickening and soreness of the skin which quickly results from repeated blistering or other counter-irritation very speedily leads to a decrease in the efficiency or a discontinuance of the procedure: whilst the electrical counter-irritation, excited directly in the subcutaneous and submucous tissues, can be carried on for months with improving results, benefiting instead of injuring the condition of the skin.

Let us now sum up the conclusions at which we have arrived, and consider their practical application.

1. It is clear that, owing to the far higher velocity of the tissue ions and their far greater numerical strength, the foreign ions, with a solution of which the pads are soaked, cannot share to any practical or appreciable extent in the convection of the current in the deeper tissues, and they either combine with the electrolytic products and so produce the so-called counter-irritation effects, or are swept away in minute quantities in the general circulation. The amount of ions that can be introduced into the system in this manner is too small to be capable of any marked therapeutic effects, except perhaps in the case of very powerful or poisonous drugs, such as strychnine, the administration of which by electrical means would be attended by considerable danger owing to the uncertain method of dosage. Further, there is no advantage to be obtained in a general medication from the more complicated electrical method than from the more simple methods of oral medication, hypodermic injection, or inunction.

2. It is clear that the local effects depend to a large extent upon the nature of the drug employed, varying from the caustic and destructive effects of zinc, copper, &c., to the mildly stimulating effects of such ions as sodium. By employing somewhat more irritating ions, such as the iodides, an equally stimulating effect may be obtained with the employment of a weak current as can be obtained by using the chlorine ions with a stronger current. And, conversely, with a stronger current, a similar stimulating effect may be obtained with a less irritating ion. That is

to say, when we employ a current up to the toleration of the patient, we shall obtain an equal amount of counter-irritation, but the toleration of the patient will be reached with a weaker current when employing a more irritating ion. But we have seen that in addition to the counter-irritation of the polar effects, the inter-polar action of the constant current is of benefit owing to the generation of heat, and the stronger the current that we employ the greater will this heat be.

These considerations afford us a guide to the solutions with which the pads should be moistened. In the treatment of a case of sciatica by the longitudinal method from the sacro-iliac region to the foot and leg, it will be most advantageous to employ a solution producing the minimum of irritation, for we shall then be able to obtain a considerable heating effect combined with the maximum of counter-irritation when we administer the current to the toleration of the patient.

In treating, on the other hand, a pre-patellar bursa with a view to the re-absorption of fluid, the heating action of the current would be of little value: in such a case it might be better to use a more irritating solution, such as that of an iodine salt. Again, if we wish to obtain a maximum effect superficially under one of the pads, it may be of advantage to paint such an area with tincture of iodine before applying the pads.

Personally, I prefer, as a general rule, to use a solution with little irritating action and to push the current to the tolerance of the patient. The toleration of the patient varies inversely as the irritating effects of the ionic products. My experience is that a solution of common salt is the most convenient one with which to moisten the pads, and the effects obtained from its use are fully equal to those obtained from more expensive and more irritating solutions.

Experience based on a correct appreciation of the action of the constant current will alone enable us to obtain the best results from this form of treatment: no fixed rules

can be laid down for its exact administration. The choice of solution must vary with the nature of the result desired. The location of the pads must be chosen in accordance with an exact knowledge of the pathological anatomy of the disease. The form of treatment must be varied from time to time in accordance with the progress of the case.

Results obtained from what may be termed the 'wholesale' lines of treatment, such as are practised at many institutes and spas, cannot equal those obtained under the personal supervision of a trained and experienced electrotherapist.

### The Surgical Application and Action of the Constant Current.

The polar action of the constant current is discussed above solely in relation to its medical application. In surgical treatment both the direct electrolytic effects of the current and the action of the nascent products of this electrolysis are of great importance.

By inserting a negative electrode, in the form of a fine platinum needle, into a hair follicle, the roots of superfluous hairs can be electrolysed, the follicle destroyed, and the hair epilated. This process is an electrolytic one, and is due both to the dissociation that occurs and the caustic action of the resulting products.

A somewhat similar method is very useful in the treatment of septic sinuses; a zinc probe is passed into the sinus and attached to the positive pole of the battery. In this case, some electrolysis of the tissues occurs, but the more important action is that of the nascent oxychloride of zinc, the product of the electrolysis, which exercises both a destructive and an antiseptic action on the lining membrane of the sinus. Lupus nodules may be successfully treated in similar manner by the introduction of a zinc needle and the application of 3 or 4 milliamperes for a few minutes.

Another application of this treatment affords us one of the most valuable methods in the whole range of electro-

therapy. In cases of chronic endometritis with a septic discharge, a uterine probe of zinc is introduced into the uterus, connected with the positive pole of the battery, and a current of 20 to 30 milliamperes is passed for fifteen or twenty minutes. No anaesthetic is needed. Any slight pain that may be caused can be allayed by a reduction in the strength of the current. In this case the nascent oxychloride of zinc pervades the whole surface of the mucous membrane, permeating to every crypt and follicle, thus destroying it more intimately and completely than can be done by the most thorough curetting. One cannot help reflecting how much better nature's arrangements are than those suggested by some electrotherapists, for were the theory of deep 'ionic medication' a true one, the whole body of the uterus would be destroyed by the action of the zinc ions.

I am convinced, both by my experience of this treatment and from my past experience of curetting, an operation which I often performed when engaged in general practice, that the electrical method should invariably be preferred, except in those cases where there is reason to suspect the presence of placental remains.

The same method can be successfully adopted in the treatment of some cases of metrorrhagia: in such cases it is advisable to use a copper probe in place of a zinc one, on account of the more styptic action of the oxychloride of copper.

The hyperplastic uterine mucous membrane is thus destroyed, and a cure effected in uncomplicated cases. I have known similar treatment successful in a case of recurrent miscarriage where the patient had several times been curetted on account of this trouble without any benefit, and had tried every precaution to prevent the recurrence of the abortion, but without effect. She took no unusual precaution during the next pregnancy after the electrical treatment, and a healthy child was born at full term. The only explanation that I can offer for the success of the treatment, after the repeated failure of curetting, is

that a diseased condition of the uterine mucous membrane had been more thoroughly removed.

Though the destructive action of the products of electrolysis is so clearly seen on superficial tissues, and though it is easy to realize the lethal action that such products must exercise on neighbouring bacteria, nevertheless, another theory has been propounded to account for this antiseptic action of the constant current.

If we pass a constant current through a capillary tube containing water, the water is electrically repelled towards the negative pole: but if the glass is coated with vaseline, the displacement of the water occurs in the direction of the positive pole. In the one case the water is positively charged in relation to the glass, and in the other it is negatively charged in relation to the vaseline.

Likewise, small particles of powdered glass suspended in water, blood corpuscles suspended in organic liquids and microbes in cultures carry an electrical charge and can be similarly transported by the constant current. Some kinds of microbes possess a positive charge and are transported towards the kathode, others have a negative charge and undergo electrical transport towards the anode.

It was hoped that this phenomenon might be of use for the purpose of differentiation between different kinds of microbes, or for separating the different kinds of germs present in the same culture. But unfortunately the electrical charge varies in amount in different breeds of the same kind of bacteria, and is often very small; sometimes even the microbes will start off gaily under the influence of the current in one direction, then stop, and afterwards set off in the opposite direction.

This phenomenon of electrical transport has not yet, I believe, been found to possess any practical value, though it is thought probable that this electrical charge of the particles may have some bearing on the phenomenon of osmosis through cellular walls. (6)

It has been suggested that this electrical transport of germs may account for the curative action of the constant

current when applied to the urethra in cases of gonorrhoea, the suggestion being that the gonococci carry a negative charge and are consequently attracted to the positive pole placed in the urethra; the increased urethral discharge which accompanies and follows the application of the treatment is cited as evidence of such a flow. This increased discharge is, of course, more readily accounted for by the stimulating action of the current on the cells of the urethral glands.

The high voltage necessary to displace the cocci from the crypts and follicles of the urethra, or to propel or attract the relatively large pus cells, appears to have been overlooked by the propounders of this theory. Certainly a new and vast field of electro-pathology would be opened up if it were possible by the 'transport électrique' to regulate the movements of the blood corpuscles and germs within the tissues of the body.

The destructive properties of the electrolytic products certainly offer a simpler and more probable explanation of the antiseptic properties of the galvanic current.

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## CHAPTER III

## THE THERAPEUTIC ACTION OF INTERRUPTED CURRENTS OF LOW FREQUENCY

IN the previous chapter the galvanic current was discussed solely in relation to that form of it which, between the periods of make and break, maintains a constant and unvarying strength.

If the galvanic current is suddenly made or broken, or if its strength is suddenly varied, entirely different effects are produced. These effects are attributable to the velocity of the hydrogen ion being five times as great as that of any other kation, and two and a half times as fast as that of any anion.

After the application of an electrical stimulus to a nerve-muscle preparation, there is a brief but measurable interval before a contraction of the muscle ensues: also, if ether be applied to the skeletal muscle of a ray fish so as to prevent the flow of ions or any variation in their concentration by electrical means, no contraction will result from an electrical stimulus, although a muscle so treated can be stimulated by the direct application of an acid or an alkali.

From these facts it is clear that the electrical action is an indirect one, and that the immediate cause of the contraction is the hydrogen or hydroxyl ion concentration which is occasioned by the abrupt make or break of the current.

Upon the establishment of an electrical current through the body there is a momentary concentration of hydrogen ions in the neighbourhood of the negative pole. This results from the relatively high velocity of these ions which causes them momentarily to concentrate at the pole towards which they are moving, i.e. the negative pole.

This hydrogen ion concentration is equivalent to an acid concentration, for the strength of an acid is in proportion to its hydrogen ion concentration. The concentration of

hydrogen ions extends backwards from the negative towards the positive pole, producing in its passage what are termed virtual poles deeply in the tissues. Diffusion of these virtual poles occurs as they spread backwards through the tissues, and consequently, their density being thereby lessened, the contractions which they excite become weaker and more diffused the further they occur from their terminal poles.

Conversely, at the moment of interruption of the current, the hydrogen ions, again owing to their relatively high velocity, become in a momentary deficiency at the point from which they are moving, i. e. the positive pole; and there is consequently a momentary excess or concentration of the more slowly moving hydroxyl ions: this is equivalent to an alkaline stimulation at the positive pole at break. This hydroxyl concentration likewise extends backwards towards the negative pole, establishing diffused virtual positive poles throughout its path.

It is clear that the old formula:—

$$K.C.C. > A.C.C. > A.O.C. > K.O.C.$$

is incorrect: for A.C.C. and K.O.C. do not occur, and the contractions attributed to them proceed from a virtual K.C.C. or a virtual A.O.C. deep in the tissues.

These points have been experimentally demonstrated by the work of Cardot and Laugier. (1) Their experiments were based on the variation with the temperature in the velocity of excitation of a neuro-muscular system. Bourguignon (2) demonstrated these phenomena in a more simple manner. Thus, if we apply a small electrode over the musculo-spiral nerve in the upper arm, and pass a cathodal closing contraction, the muscles in the forearm supplied by the musculo-spiral nerve will be excited. If, however, we employ an active positive electrode with a closing contraction at the same spot, only the muscles of the upper arm (irrespective of their nerve supply) in the immediate neighbourhood of the electrode will contract. In the former case there has been a direct stimulation of the musculo-spiral nerve—a true K.C.C. In the latter case there has

been no stimulation of the nerve, but an excitation of the muscles in the neighbourhood of the electrode by a virtual K.C.C. deep in the tissues.

The amplitude and vigour of the muscular contraction vary with the degree of ionic concentration: this in turn varies with the voltage and with the rapidity or abruptness of the make or break. The concentration is only a momentary one, for ionic equilibrium is almost at once re-established both at the terminal and at the virtual poles, and the higher the voltage the more rapid is the re-establishment of this equilibrium. The concentration is continuously repeated while the voltage rises or falls.

To obtain the necessary concentration of ions for the excitation of a contraction, two conditions are required. 1. The current must have a certain minimal strength, or no contraction can be excited. 2. The current must have a certain minimal duration, below which a current of a given strength will not excite a contraction. If the minimum duration of a current of the minimal strength is reduced, no contraction will result; and as the duration is decreased the minimal strength of the current has to be increased in a rapidly increasing ratio. The converse of this holds good, and if the voltage of a current is increased, a contraction is obtainable at a lower amperage.

If, instead of employing an abrupt make and break, we make or break or increase or lower the strength of the current very gradually, as is done in the administration of the constant current, there will not exist at any moment sufficient ionic concentration to excite a contraction; the higher the voltage, the more gradually must the current be applied in order to ensure the absence of excitation.

These points can be illustrated by analogy with the flow of water. If we imagine a volume of water held back by a dam at a high level (high potential), it is clear that entirely different effects will be produced if we allow the water to trickle slowly through the dam, or if we suddenly open a large flood-gate and allow the water to rush through with high velocity and great force. In the former case very little

energy can be utilized, in the latter, the density or concentration of the energy is very high. These effects are analogous to the slow and gradual application of a high potential, and to abruptly making or breaking the circuit.

The contractions occurring at the make and break of a galvanic current are single contractions, and while the current is maintained at an even strength no further contractions result. The single snatch of a muscle which is thus obtained is not of the best type for ordinary therapeutic purposes. A physiological contraction is of a tetanic type resulting from the rapid succession of repeated stimuli, occurring not less frequently than about twenty a second. In order to excite contractions of this physiological type, the faradic coil is usually employed. In this instrument a rapidly vibrating trembler blade makes and breaks the primary current fifty or more times a second. This interrupted current passing through the primary coil induces a secondary current of similar frequency, but of very brief duration and of far higher voltage in the secondary coil.

This increased voltage in the secondary is proportional to the increased number of turns or coils of wire in the secondary coil. As the voltage is increased in this way, the amperage of the current is correspondingly decreased. The faradic current at break is in a contrary direction to that at make, and is so much more powerful that for practical purposes the current at make may be disregarded. The faradic current differs from an interrupted galvanic current in the following respects: the voltage is far higher than that ordinarily applied in galvanism; polar action is absent, for the amount of current that passes at make being less abrupt takes longer to flow; and so, though its voltage is lower, an equal amount of current passes at each interruption, distributed over a longer period, with the result that the polar effects of the current at make neutralize the polar action of the current at break, and vice versa. There is, however, this similarity between the action of the two currents, that, provided it is interrupted with sufficient rapidity, a tetanic contraction can be ex-

cited by the galvanic current. Such a tetanic action can be readily obtained by the ingenious arrangement known as the Frimandeau coil. This is an instrument that utilizes the magnetic attraction of the core of the primary coil of the faradic to interrupt the galvanic current.* The current so obtained has one definite advantage over the secondary current from a faradic coil. The current obtained from the usual clinical type of faradic coil has a duration of only about 1/1,000 of a second: the duration of the current from the Frimandeau coil may, on the other hand, be varied within wide limits by the adjustment of its interrupter. The duration of the faradic stimulus is too short to excite a contraction in a muscle, the nerve of which is not functioning, but the interrupter of the Frimandeau coil may be so adjusted as to give interruptions of sufficient frequency to excite a tetanic contraction, and of sufficient duration to stimulate a paralysed muscle. The current from such an instrument has a polar action, and, its voltage being lower, the intensity needed to excite a contraction, corresponding in range to that from a faradic stimulus, must necessarily be greater. On account of the lower voltage employed, the contraction excited by the Frimandeau coil is less painful than that from the faradic coil; moreover, being unidirectional, it admits of measurement by an ordinary galvanometer.

The high voltage of the current from the faradic coil can be utilized to excite counter-irritation of the skin: in this case the current is best applied by means of a wire brush or Tripier's 'râteau'. This skin effect is, however, far better obtained from a high-frequency apparatus of tension or a static machine.

* The Frimandeau coil is arranged in the following manner. One of the rheophores is divided, and one of the divided ends is attached to the pillar supporting the adjustable platinum tipped screw, the other end is attached to the pillar supporting the trembler blade of the primary coil. In this way when the trembler is attracted by the magnetism of the core, the galvanic circuit to the patient is broken: when the core is re-magnetized, the trembler flies back and re-establishes the circuit.

The faradic current may hence be regarded for therapeutic purposes mainly as a means for the artificial stimulation of muscular contraction and muscular exercise. Its use is indicated in that large class of cases where muscular exercise is likely to be beneficial: in cases of obesity, of wasted or flabby muscles, of dilated heart, of oedema of the extremities, in certain cases of rheumatism, constipation due to laxity of the abdominal walls, and a variety of similar conditions.

In its application for the excitation of muscular contraction, the faradic current should alternate with periods of rest several times a minute; $\frac{2}{5}$ duration of current to $\frac{3}{5}$ rest is a safe rule. Otherwise, were the current applied with no intervals, the muscle would be over-fatigued, and more harm than good would result from the treatment. It may be interrupted and restarted, either suddenly and abruptly as by a metronome, or in a graduated wave or surge, either manually or instrumentally.

The work of Morton Smart and Rowley Bristow has shown how, and with what benefit, individual muscles may be developed; and the very important work of the distinguished electrotherapist, Professor Bergonié, of Bordeaux, has demonstrated with what advantage to the whole body this system may be utilized as a curative agent. Professor Bergonié's method was originally introduced for the treatment of obesity, in which condition about a pound of weight or more is lost by a fat patient as the result of the fat being burnt up in the energy expended by the muscular contractions during a single treatment. The loss in weight is accompanied by an increase in the muscular tone and development, and a marked improvement results in the general health of the obese patients. This treatment has recently been extended to many other conditions, and is of special value in the treatment of dilated hearts associated with a general deficiency in muscle tone, for the muscles of the body can be exercised by this method without any muscular strain or nervous effort on the part of the patient, the rate and vigour of

the contraction being under the complete control of the operator.

The alternating and sinusoidal currents in their therapeutic action closely resemble the faradic current. The term 'alternating' implies that the direction or polarity of the current alternates from positive to negative, and vice versa; these alternations are usually at the rate of about fifty times a second. In consequence of this alternation the polar effects of the current mutually neutralize one another. The term sinusoidal implies that this variation in direction occurs gradually in the form of a 'sine', or wave-like, curve. Wave-like contractions can by this means be excited in the muscles, varying in degree, according to the strength of the current, from a gentle tremor to a vigorous contraction.

The therapeutic action of interrupted currents, such as the alternating and sinusoidal, differs from that of the continuous current in some very important respects. Since in currents with frequent reversals of polarity the polar action is neutralized at each alternation of direction, little or no therapeutic effect will result from this cause. Again, owing to its intermittency the heating effect on the tissues will be far less with the alternating than with the continuous current. The therapeutic action of interrupted currents is mainly due to the recurrent hydrogen ion concentration which results from their intermittency. At each make and break, at each sudden variation in their strength, a concentration of ions occurs throughout the tissues, and this, though it may not be of sufficient amount to excite a muscular contraction, has nevertheless a stimulating effect on the cells of the body. Dr. Barclay, of Manchester, published during the war some very interesting results that he obtained from treating cases of un-united fracture by the sinusoidal current. By a series of radiographs he was able to show the extent to which callus formation was increased by the treatment.

As the result of this recurrent ionic concentration, the alternating currents are far more dangerous than the

continuous, and fatal accidents occur at considerably lower voltages with them.

Alternating and sinusoidal currents, owing to the ionic concentration that they excite, should never be employed in regions near the heart. In Germany several deaths have been recorded from fibrillation of the cardiac muscle excited by even the small sinusoidal currents derived from machines of the pantostat type.

Some very remarkable results have been claimed for a form of interrupted current, known as the Leduc current. The Leduc interrupter is an instrument that admits of the interruption of the galvanic current up to two hundred times a second, the best results being obtained at about half that rate of interruption. It is claimed that by employing this form of interrupted current it is possible 'to produce gradually with remarkably weak currents single contractions, tetanus, local anaesthesia, general anaesthesia, paralysis of the respiration, of the heart, and ultimately death'.

Leduc claims to have produced all these results when experimenting on animals, prolonging the anaesthesia for eight hours in some cases without producing any bad effect. He has also, when experimenting on himself or his assistants, produced anaesthesia and 'electric sleep'. The intensity of the current does not exceed three or four milliamperes, and the potential is only from ten to twenty volts.

There does not seem to be anything occult in these experiments; their chief scientific interest lies in the fact that they show the cumulative effect of the recurrent ionic concentration excited by very weak currents when rapidly interrupted. Whereas, with interrupted currents of high or even moderate intensity, a sudden inhibition of respiration or cessation of the heart beat would occur, on the other hand, when using a current of low tension and intensity, we are able, in consequence of its cumulative action, slowly and gradually to produce in animals these results, and at the same time can differentiate the various stages produced by its action.

Electrotherapists, who have succeeded in producing cutaneous anaesthesia upon themselves in this manner, tell me that the procedure is a very painful one; the anaesthesia is, moreover, by no means easy to produce, and physiologists frequently fail to obtain it in laboratory experiments. The anaesthesia, local or general, would appear to be due to an over-fatigue of the sensory organs in the one case and of the brain cells in the other. The local anaesthesia is in many respects identical with that obtained by rapidly and repeatedly percussing a skin area.

The Leduc interrupter can be utilized for electrodiagnosis of nerve and muscle injuries, and is very convenient for this purpose, as by its use the duration of the current can be readily regulated, and its intensity can be measured by a milliamperemeter.

These currents are useful in the treatment of certain forms of neuritis. In causalgia, in my experience it far surpasses all other forms of treatment, relieving for several hours the intense pain of this terrible condition with such certainty as to have even a diagnostic value. It appears possible that by the repeated stimulation of the hydrogen ion concentration, resulting from this treatment, the sensory organs, already in a state of hyper-activity, may become exhausted and so anaesthetic; in a way analogous to that in which the recovering end-plates of motor nerves in peripheral nerve lesions become readily over-fatigued and inexcitable, when subjected to too frequently repeated electrical stimulation.

We have seen that, provided the galvanic current is applied to a limb with very slow gradation from zero to the maximum strength employed, no muscular contraction will be excited; but if the current is applied rapidly or suddenly, a contraction at once results. As a current increases to its maximum more and more gradually, so the efficiency of the resulting contraction diminishes, until no contraction results. Lapicque has shown that paralysed muscles, needing a larger stimulus to excite them and a longer duration of the minimal strength of this stimulus

than normal nerves and muscles, are less adversely affected than the latter by a retardation in the onset of the current.[1]

Though, for instance, a current which reaches the minimum exciting strength in about 1/200 second may fail to excite a contraction in a healthy muscle, yet a current which takes as long as 1/20 second to reach the minimal exciting strength may nevertheless stimulate a contraction in a paralysed muscle. On these principles Lapicque has introduced an instrument (Fig. 7) by means of which the current reaches the necessary strength so gradually that the paralysed muscles are excited to contract, while the healthy muscles remain unexcited. This is a most valuable result, for not only is all fear of the over-action of the healthy muscles entirely eliminated, but also the isolated contraction of the affected muscles has a most valuable re-educative effect on the patient in recovering nerve lesions. For by this means the movement that the patient has to re-educate himself to perform is clearly demonstrated to him.

Lapicque produced this retardation of the onset of the current by means of condensers. For the application of this treatment the following apparatus is needed: a source of constant current supply; an arrangement for regulating the current, either a graphite or a water resistance, a wire-wound resistance must not be employed on account of the secondary induction which would be set up by use. There is also needed an instrument, such as a metronome, for interrupting the current, and finally a set of fifteen condensers[2] of 2 M.F. capacity placed in parallel with one another and in parallel with the patient. These condensers should be fitted with a selector enabling any multiple of 2 M.F. capacity to be employed up to the maximum of

[1] 'If a current reaches progressively its constant intensity, the diminution of its efficiency, which is the result of this slowness of make, is smaller as the chronaxie is longer' (Lapicque, *Académie des Sciences, Comptes Rendus*, November 22, 1915).

[2] 'A condenser of 1 M.F., placed in parallel, causes the current to take about 3/1,000 second to reach 95 per cent. of its intensity constant' (Lapicque, *Académie des Sciences, Comptes Rendus*, November 22, 1915).

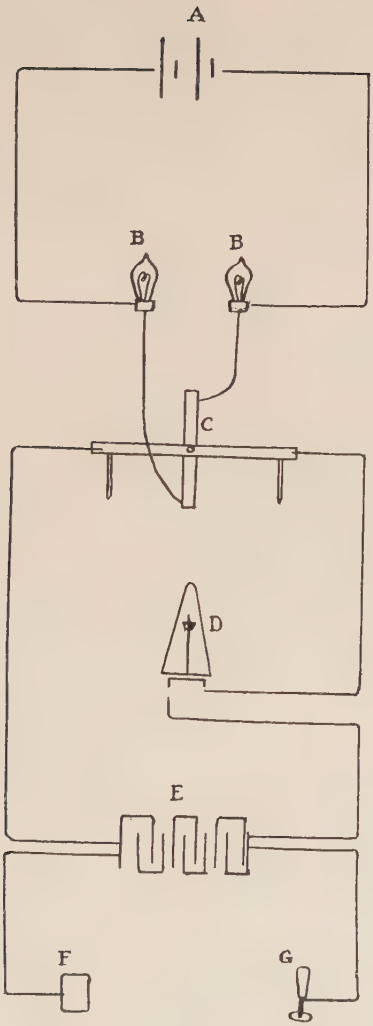



FIG. 7. A modification of Lapicque's instrument for the selective stimulation of paralysed muscles.

A. Source of current supply. B. Resistance lamps.
C. Water resistance. D. Interrupting metronome.
E. Condensers. F. Indifferent electrode.
G. Active electrode.

30 M.F. The larger capacities are employed as the lower excitability of the patient's muscles necessitates the employment of a more prolonged exciting current. The apparatus operates in this manner; at the make of the current a gradually decreasing amount of the current, which would otherwise have reached the patient, is diverted into the condensers placed in parallel with him, until they become fully charged, when the full current passes to the patient.

When the metronome breaks the current, as there is no path for the condenser discharge except through the patient's circuit, the condensers discharge with a gradually decreasing intensity in the direction of the current of make, and so damp or lengthen the current of break in proportion to the condenser capacity employed. A gradually progressive current both at make and break is thus obtained.

A somewhat similar effect, but one which is not capable of such easy and effective adjustment, can be obtained from certain types of surgers.

It is convenient to regard, from the therapeutic point of view, condenser discharges as a form of interrupted current; for by repeatedly charging and discharging a condenser a result is obtained in many respects identical with that from making and breaking a galvanic current. By charging and discharging a condenser through a patient at intervals longer than twenty a second, distinct and isolated contractions are obtained; or the condenser may be charged and discharged with such frequency that a tetanic contraction results. By means of the so-called Static Induced Current of Morton an isolated or a tetanic contraction can be obtained as desired. The character of a condenser discharge depends upon the resistance offered to the discharging current. If the resistance in the circuit through which the discharge takes place is negligible or very slight, the current rushes from the condenser so rapidly that it over-discharges itself, and then oscillates so rapidly with decreasing amplitude, before it finally comes to rest, that it gives rise to a high-frequency current in the manner described in the next chapter.

But, if the current from the condenser discharges through a high resistance, the discharge takes place in an unidirectional wave falling in voltage rapidly at first and then gradually subsiding to normal. The duration of such a discharge is in any case very brief, varying with the capacity of the condenser, the voltage at which it is charged, and the resistance through which the discharge takes place.

A condenser of 0·016 M.F. capacity charged at a potential of 100 volts, discharging through the resistance usually offered by the human skin, takes about 1/24,000 second to discharge. A condenser of one farad capacity is one which is raised to a potential of one volt by a coulomb of electricity. In medical electricity we employ micro-farads and their fractional parts, the micro-farad being 1/1,000,000 of a farad. The amount of current which is employed is therefore extremely small, but owing to the high potential used a condenser of 0·025 M.F. charged at 100 volts is capable of exciting a contraction in a normal muscle.

Condenser discharges are recommended by some electrotherapists for the purpose of electro-diagnosis; they are especially useful perhaps in examining cases of infantile paralysis, the smaller condenser discharges being less painful than the faradic current. The degree of paralysis can within certain limits be roughly estimated by the use of discharges from condensers of varying capacity.

The use of condenser discharges has from time to time been recommended in electrotherapy, but it is difficult to understand what advantages their employment possesses over the less complicated faradic coil, the latter having the advantage of being more readily adjusted to excite a tetanic contraction, and also in yielding no polar action on the skin, though such polar action must be very small with condensers, on account of their small capacity. The most important therapeutic effects from condenser discharges are those obtained from the static induced currents of Morton, in which the enormously high potential employed enables certain effects, which are discussed in

the chapter on Static Electricity, to be conveniently obtained.

The Watteville Current is a faradic current reinforced by a constant current flowing through the secondary of the coil in the same direction as the current of break (the Watteville Current 'in tension'). If the direction of the constant current is reversed, its effect is to weaken the action of the faradic current (the Watteville Current 'in opposition'). As ordinarily applied, a faradic coil is inserted in a galvanic circuit, so that the positive pole of the faradic secondary at break is connected with the negative wire from the galvanic battery, and the positive of the battery with the negative of the secondary coil. The current from the battery in this case flows in the same direction as the secondary current of the coil at break; it thus enables a faradic contraction to be excited with less sheathing of the primary, and, consequently, at a lower voltage, and with less pain, an effect of the same character as is obtained by replacing a finely wound secondary by one wound with coarser wire. The Watteville Current 'in tension' is recommended by some writers for the excitation of involuntary muscular fibres, but it is incapable of such action. It is a useful method of obtaining a tetanic contraction at low voltage, and excites a very efficient form of muscular contraction when suitably surged.

The Watteville Current 'in opposition' is very little employed; the higher voltage necessitated by its use is more painful and thus excites greater counter-irritation of the skin.

A constant current may be interrupted suddenly and abruptly, as by a metronome, or by a switch; or it may be gradually increased in strength to the maximum from zero, and gradually back to zero; when applied in this manner it is said to be 'surged'.

Either the metronome or the surger may be so arranged as simply to make and break the current, or they may be adapted to reverse the direction of the current each time it is interrupted, and so obviate polar action on the skin.

On general grounds the metronome method of interruption is to be preferred for the excitation of a powerful and sudden type of contraction; for, since there is in this method no retardation of the onset, the resulting contraction is more efficient.

The surging method should be selected when a gradual, painless, and wave-like contraction of the usual physiological type is desired. The sudden quick contraction excited by the metronome appears to be more suitable for the treatment of obesity, and the slow surging method of interruption for the development of muscle.

An instrument for the surging of therapeutic currents should fulfil the following requirements:

(1) It should admit of wide variation in speed, a slow speed for surging the faradic and sinusoidal currents, and a faster surge, readily regulated, to admit of its employment in place of the Lapicque condensers for the selective stimulation of paralysed muscles.

(2) It should admit of the polarity being reversed at each interruption, in order to obviate polar action on the skin.

(3) It should allow of a definite and adjustable period of rest between each stimulation.

(4) It should allow of the current remaining at its maximum for a definite period, the duration of which should be capable of regulation.

In order to meet these requirements, I have designed an instrument (Fig. 8), electrically driven, which admits of its speed being regulated, (1) by three steps in the relation of the driving pulley to the driven pulley, (2) by adjusting a friction disc drive, (3) by regulating the rheostat of the driving motor.

A horizontal vulcanite disc, revolving in a bowl of water, bearing two contact wires, reverses the polarity, if desired, at each interruption, and both the periods of rest and maintenance of maximum intensity can be regulated by increasing or diminishing the length of these contact wires.

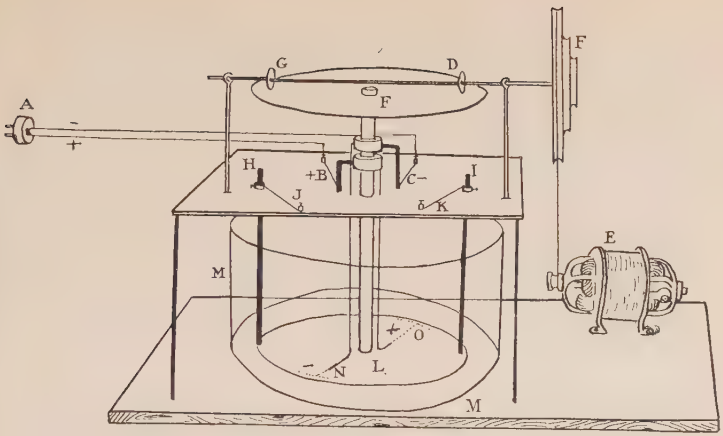
This instrument may be utilized for surging any form

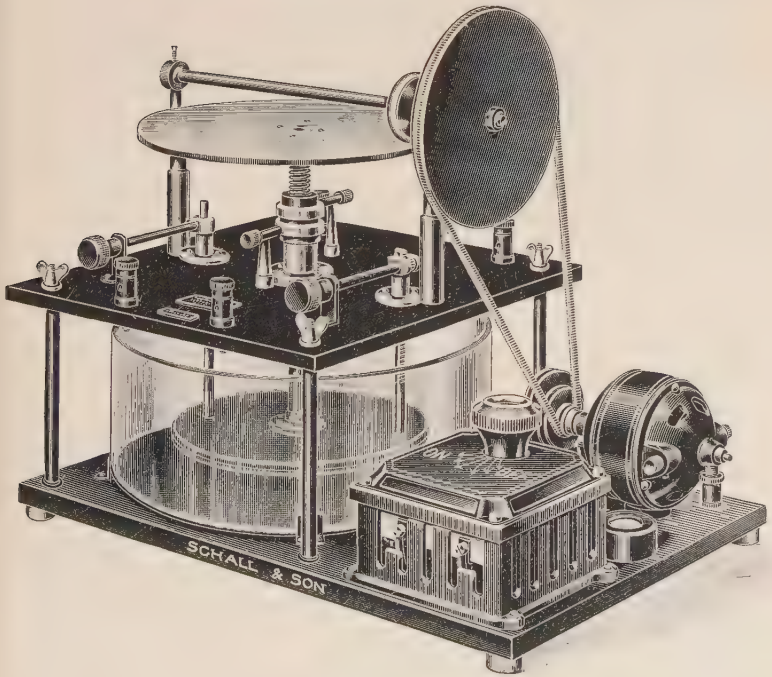
of current, but it is especially useful when applying the Watteville current.

When used with this form of surger, the galvanic current, being reversed at each half-revolution of the disc, is alternately in tension and in opposition with the sinusoidal or faradic current. Consequently, if an electrode is attached to each leg, the muscles of either limb will alternately contract and relax, as in walking: the resulting movement is thus a more natural one than when the two limbs move at the same time. By connecting and so shorting the terminals C K, a stronger stimulus will be obtained, but in this case there will be no reversal of the current and no alternation of the contraction. The first of these two methods is the more suitable for weak stimulation and for the treatment of sciatica and oedematous conditions, such as 'white leg'; the latter method is the more suitable where stronger muscular contractions are desired.

Although many special forms of current at varying rates of interruption have been designed and recommended by electrotherapists for exciting contraction in the involuntary muscles of the intestines, the fact nevertheless remains that the involuntary muscles of the stomach and bowels are incapable of excitation by any of the currents employed in electrotherapy. Several causes may contribute to this. In place of the simple excitatory mechanism of voluntary fibres, we have in the intestines a double mechanism of excitory and inhibitory nerves: in place of the relatively simple contraction of voluntary muscle, we have the peristaltic movement of the intestinal muscle communicated from fibre to fibre: the quick chronaxie of voluntary muscle is replaced by the slow chronaxie of the muscles of the intestines: and, finally, in the abdomen we have a wide area for the diffusion of the current in place of the relatively circumscribed area of a limb.

This absence of response in the intestinal muscles is, perhaps, fortunate, for otherwise the intestinal colic that would be excited would render incapable of administration




FIGS. 8 and 9. The author's surger.

A. Wall connecting plug. B and C. Terminals in connexion with rubbing contacts on revolving spindle. D. Friction drive wheel. E. Motor. F. Revolving disc. G. Balance friction wheel. H. I. Brass dipping rods connected with terminals JK. L. Revolving vulcanite disc. M. Circular glass bowl. N. O. Wires to periphery of revolving vulcanite disc.

(In practice it is better to connect the patient with terminals B and C, and the source of supply with the terminals J and K. This arrangement prevents the rapid destruction of the wires N O by electrolysis from the shunt current.)

such electrical treatments as those for obesity and those for restoration of tone in the abdominal muscles.

It is, however, possible to treat indirectly by electrical means certain forms of chronic constipation with considerable success. For the rhythmic pressure and increase of tension produced by the excitation of slowly surged contractions in the abdominal muscles will doubtless stimulate peristalsis. Again, by the restoration of tone to the abdominal muscles the cause of constipation in enteroptosis may be entirely removed.

Interrupted currents exercise no appreciable action on the larger blood-vessels, but the clearly beneficial effects produced by application of a suitably surged current on cold and oedematous limbs are probably due partly to the stimulating action on the walls of the arterioles by the electrically induced hydrogen and hydroxyl ion concentration. This effect on the arterioles is probably of a similar nature to the action of contrast baths on the more superficial arterioles—an action which is well expressed by the term, suggested by Sir Robert Jones, 'gymnastics of the arterioles'.

It is difficult to say to what extent the beneficial effects of electrical stimulation of tissues of low excitability are due merely to the increased blood-supply, and to what extent they may be due to a direct stimulation of the tissue cells.

For the restoration of muscular tone—a category which covers a very wide and important range of cases—no other procedure equals in its results those obtained from the use of the surgical faradic current in accordance with the plan introduced by Dr. Morton Smart. The importance and special value of this treatment call for some further consideration of its mode of action. The value of the treatment is perhaps most clearly seen in cases of loss of muscular tone following the tearing of a few muscle fibres in cases of rider's strain. In these cases, although the actual lesion may be a very slight one, producing no physical signs beyond some tenderness at the seat of the lesion, yet

the muscle tone is found to be almost completely lost in the group of the three adductors, their electrical excitability is much reduced, and adduction of the affected thigh, such as gripping a horse, causes sufficient pain to lead to a speedy abandonment of such movement. With no treatment other than rest and bandaging, the condition is prolonged for months, and ultimately it is necessary to adopt some supporting instrument to overcome the pain induced by horse riding.

In the treatment by the Morton Smart method of these and similar cases, such as loss of tone in the quadriceps muscle following injury to the knee joint, the condition of the muscles improves far more quickly than would be anticipated or than can be accounted for by a simple restoration of strength due to a re-development or regeneration of muscle tissue.

Hitherto it has been difficult to explain this speedy recovery. A possible explanation can, however, be deduced from the recent experiments of Dr. E. D. Adrian (3) on the action-currents produced by sensory nerve endings. By means of an extremely delicate electrometer capable of reacting to a potential variation of 0·01 millivolt lasting for 1/1,000 of a second, Adrian was able to record the passage of action currents 'accompanying afferent impulses in the sciatic nerve of the frog when the gastrocnemius is stretched by a weight, in the cat's saphenous nerve when the skin is pinched, in the vagus of the cat and the rabbit when the lungs are inflated, and in the cardiac depressor nerve of the rabbit with each heart beat'. (4)

'Impulses are started from different sense organs irregularly. A single end-organ, however, responds to a continuous stimulus with a regular series of discharges. Their frequency varies from 5 to 100 a second.' (4)

The law of 'all or nothing' is found to apply in these experiments, for each contraction is a maximal one; the frequency of the action-currents varies, however, with the strength of the stimulus. When the muscle is slightly loaded and is comparatively slack, stimuli still pass up the

nerve at a frequency of about 3 to 8 per second. It has been suggested that such stimuli are the basis of tone in voluntary muscle.

It might further be argued, that when a muscle had lost its tone from injury to its fibres or to a joint with which its action is associated, these afferent stimuli in the sensory nerve would be slight or absent. And, as time went on, from the absence of such stimuli a further loss of tone in the muscle would occur and would tend to be increased by too long rest or splintage of the affected part. Thus, a vicious circle would be established which would fully account for the lack of recovery in tone in the muscles of injured limbs which have been too long treated by rest and fixation. By the strong, graduated contractions excited by the Morton Smart coil, stimuli are applied to the muscle tendon, which in turn set up these action currents, and in this way rapid restoration and maintenance of muscle tone can be rationally accounted for.

For the relief of nearly all forms of pain, the method of choice is unquestionably the diathermy current. The chief exception to this rule is the relief of that peculiarly painful condition known as causalgia, in which diathermy exacerbates the heat-pain, for which the Leduc current acts as a specific.

For the excitation of weak, painless, and slow rhythmic contractions, and for the stimulation of tissue of low and slow excitability, the surged Watteville current is indicated. This form of treatment is useful for the restoration of tone in muscles which have become flabby as the after-effect of sciatica or neuritis, when the more vigorous contractions excited by the Morton Smart coil are perhaps too powerful. It is also most useful in the resolution of the indurated oedematous conditions following phlebitis and associated with 'white leg', and also for exciting tissue stimulation in chilblains and allied conditions. The special physical properties of this current are due to the prolongation of the period of excitation.

Perhaps our terminology or our mode of expression may

be misleading, for when we speak of the excitation of muscular contraction being due to a sudden concentration of hydrogen or hydroxyl ions, we do not mean that this is a sudden isolated concentration, but that it is a continuously recurring concentration lasting while the voltage is abruptly rising or falling; and that it is due to the continuous arrival of fresh 'parcels' of hydrogen or hydroxyl ions, whilst previous parcels have been or are being neutralized during this period of varying voltage. In the break current of the faradic coil this concentration is condensed into about 1/1000 of a second, in the Watteville current it may extend to 1/50 of a second or more.

The Watteville current, strictly speaking, implies the combination of the galvanic current with the faradic, but the term is also applied to combination of the galvanic with the sinusoidal current, and in this latter form it is the more useful for the excitation of tissues of low excitability, owing to its more prolonged wave of excitation. The addition of the galvanic current to the sinusoidal increases the voltage of the combined current, but the prolongation of the wave of excitation thus obtained is the more valuable effect of the combination. With this current a condition is produced very similar to that which occurs with the selective galvanism of Lapicque, in which the prolongation of the wave of stimulation is more favourable to the excitation of muscles with a slow, than to those with a quick chronaxie.

The type of muscular contraction produced by the Watteville current is more wave-like and less abrupt than that produced by a sudden make and break of the current, and this slower type of muscular contraction is more suitable for certain purposes, such as the stimulation of the abdominal muscles in the treatment of constipation and in the dispersal of oedema from the limbs.

The resulting waves of muscular contraction are not, however, so dependent upon the type of the isolated stimuli as upon the manner in which the tetanic contractions excited by rapid repetition of these stimuli are

applied. The current exciting these tetanic contractions must be gradually surged on and off, allowing sufficient time between each tetanic contraction for an adequate period of rest. It is also well to select a surger which will reverse the polarity of the galvanic component at each alternate group of contractions; in this way all risk of an electrolytic burn will be avoided.

Administered in this manner, the Watteville current is one of the most useful employed in electrotherapy.

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## CHAPTER IV

## THE THERAPEUTIC ACTION OF INTERRUPTED CURRENTS OF HIGH FREQUENCY

AS the outcome of his investigations on the physiological action of alternating and sinusoidal currents, D'Arsonval (1), in 1888, found that by increasing the number of interruptions or waves administered in tetanizing a muscle, the intensity of the phenomenon of excitation was correspondingly increased, until a maximum of from 2,500 to 5,000 excitations a second was reached; after this point an increase in the frequency caused a decrease in the degree of excitation. At that time D'Arsonval was using a Ruhmkorff coil, and was unable, owing to the time lost in magnetizing and demagnetizing the core, to obtain a sufficient frequency of oscillation entirely to suppress muscular contraction. In December 1890, using the apparatus of Hertz, D'Arsonval obtained 'billions of electrical excitations a second', and was thus enabled to suppress all muscular contractions, and hence was the first to demonstrate the characteristic phenomena of high-frequency currents.

Other papers and experiments by D'Arsonval, by Zeyneck in 1899, by Bordier and Lecomte in 1900, developed our knowledge of the physiological action of high-frequency currents. But, although Tesla, in 1891, had demonstrated the predominating influence of the heating effects of these currents, it was not until after the publication of Nagelschmidt's remarkably complete and exhaustive monograph, 'Lehrbuch der Diathermie', 1913, that much attention was paid by electrotherapists to the therapeutic importance of the healing effects of high-frequency currents.

The discovery of the high-frequency currents as applied to therapy, their evolution into the diathermy currents, and the perfection of the instruments employed in their application could not have been accomplished,

but for the genius of those eminent physicists by which the marvels of modern wireless telegraphy and telephony have been revealed.

The basic principles of the instruments employed in wireless and in medical H.F. currents are practically the same, and a study of the principles involved in the construction of a wireless transmitter is perhaps the best method of acquiring a practical understanding of the physical basis of the H.F. and diathermy currents.

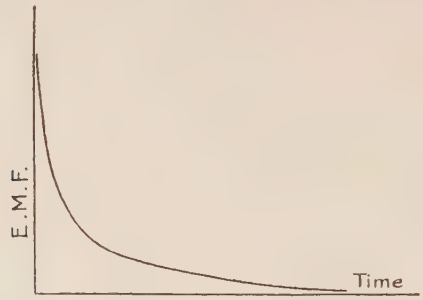


FIG. 10. Type of condenser unidirectional discharge through a high resistance.

Both H.F. and diathermy currents need for their operation the following components:

1. A supply of alternating current. This is usually obtained from the A.C. mains, but if an A.C. supply is not available a rotary transformer is needed to convert the D.C. supply into A.C.

2. A step-up transformer to raise the voltage sufficiently to overcome the resistance of the spark gap.

3. A spark gap across which the condensers, when fully charged, can discharge.

4. Condensers to store up the charge, until sufficiently charged to overcome the resistance of the spark gap.

A condenser discharges itself in one of two very different manners. If the resistance through which it discharges is high, the current of discharge is of a slow, continuous, progressive, and undirectional character (Fig. 10). If the

resistance is negligible, the discharge is of an oscillating character, the oscillations being isochronous, and decreasing in amplitude in geometrical progression (Fig. 11). These two types of discharge have been well compared to what takes place when two vessels filled with water are connected in the one case by a pipe of large diameter, and consequently of negligible resistance or friction; and in the other case by a pipe of small diameter, which consequently offers considerable frictional resistance.

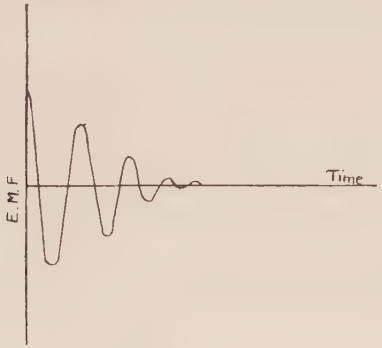


FIG. 11. Type of condenser oscillatory discharge through a low resistance.

In the former case the water reaches the point of equilibrium, after overlapping it, in a series of progressively diminishing oscillations. In the latter case the point of equilibrium is slowly, steadily, and progressively reached without at any time being overlapped. The first example serves to illustrate the type of discharge which is required to excite the very frequent oscillations necessary for the production of high-frequency currents. The latter illustrates the type of condenser discharge which is sometimes used for electro-diagnosis, and also for treating cases of paresis and paralysis by intermittent condenser discharges of low frequency: in such cases the discharge takes place through the high resistance of the skin, and hence is of the continuous type shown in Fig. 10.

5. A solenoid. The solenoid of the D'Arsonval H.F.

apparatus consists of a coil of copper tubing, 8 inches in diameter, with 20 turns separated from one another by a space of about $\frac{3}{8}$ of an inch.

The spark gap of the apparatus, in accordance with the plan of D'Arsonval, should be placed in parallel between the transformer and the condensers.

In the H.F. apparatus, the alternating supply and the transformer may be replaced by the high voltage current from an induction coil; but for the production of diathermy currents, this arrangement is not so satisfactory as the alternating current combined with the step-up transformer.

A high-frequency apparatus functions in the following manner: the condensers, when they have been charged to a sufficiently high voltage to overcome the resistance of the spark gap, discharge across this gap. The discharge, after the resistance of the spark gap has been overcome, oscillates over past zero (as in the analogy quoted with the water supply connected with pipes of large diameter), and, by this oscillation or over-discharge, recharges the condensers with the opposite polarity to an extent very little less than their original charge. Another discharge in the opposite direction then takes place, and the condensers are again charged in a similar manner. This process is repeated with diminishing energy, until the condensers are fully discharged, a process again analogous to the simile of the water supply. The first sparks across the gap create an ionized path for the subsequent sparks, and so, by diminishing the resistance across the gap, considerably facilitate the H.F. oscillations. When fully discharged, the condensers are recharged by the alternating supply at each of its alternations: thus, if the supply has a periodicity of 50, the condensers are recharged 100 times a second. The cycle is then repeated.

Whilst the condensers are discharging, the current passing through the solenoid sets up H.F. oscillations in it, and these are in turn damped out by the self-inductance that they set up.

The more numerous the turns in the solenoid, the greater is the self-inductance. The greater the self inductance, or, the greater the capacity of the condensers the lower will be the frequency of the oscillations.

Only a minute fraction of time is occupied by the discharge of the condensers. Its duration depends on (1) the resistance of the oscillatory circuit, which in the H.F. circuits is extremely minute; (2) the capacity of the condensers; (3) the self-inductance. A calculation, based on the formula of Lord Kelvin, shows that such a H.F. discharge may only occupy 0·00125 of a second.

The modern diathermy apparatus has been evolved from the older type of high-frequency apparatus by alterations of the spark gap, the condensers, and the solenoid.

The spark gap, instead of consisting of two small metal balls or points, separated by a relatively large interval, has been replaced by a new form of gap formed by circular metal plates, composed of tungsten in the more recent machines, separated from one another by a millimetre or less. To effect cooling, and so prevent arcing, they are either fitted with radiating flanges or with a coal-gas container, and are arranged in a multiple series.

As the result of decreasing the width of the gap, the condensers discharge at a relatively low voltage, and may be thus discharged two or three times at each alternation of the primary current, thus setting up two or three trains of oscillations in place of the single train obtained across the wider gap of the old type of H.F. spark gap. In this way the amperage is much increased.

In place of the former type of solenoid, a flat spiral of metal is now usually employed, and the strength of the current administered to the patient is regulated by approaching or removing a similarly arranged coil, to the ends of which the patient's rheophores are attached. This is termed loose-coupling. There are, however, many modifications of this arrangement.

The modern machine yields a higher amperage at a

lower voltage (H.F. currents of quantity); the older type yielded a lower amperage at a higher voltage (H.F. currents of tension).

As the result of these modifications the modern apparatus yields oscillations of a more sustained or less damped type; and these oscillations, though still slightly damped, are sufficiently sustained to yield a satisfactory output for the ordinary requirements of the electrotherapist.

Early in 1919, the author approached one of the leading firms engaged in the construction of radio-valves, with a view to the construction of an apparatus fitted with three electrode valves, in order to obtain a machine that would yield fully sustained oscillations. The cost of the two power valves required at that time proved to be £28; and, as it was anticipated that they would break down after a brief period of use, in view of the cost of the apparatus, and, so far as was then known, its doubtful advantages, further experiments were abandoned.

Recently, however, as the outcome of improvements in the structure of the valves, and a decrease in their cost, several machines, on somewhat similar lines to the one contemplated, have been placed on the market in France, Holland, and America. They appear to possess certain very definite advantages, and it is probable that, in the course of time, they will replace the existing type of diathermy apparatus. Bordier, to whom the perfection of the three electrode valve apparatus is in a great measure due, thus summarizes its advantages:

1. Low consumption and great output.

Whereas the best of the spark gap machines do not yield a greater output than 30 per cent. maximum, the arrangement with the three electrode valves gives an output varying from 50 per cent. to 70 per cent. For a current of 5 amperes furnished by an in-put of 110 volts, the power available in the H.F. circuit is

$$5 \times 110 \times 0{\cdot}7 = 385 \text{ watts.}$$

2. The apparatus is absolutely silent.

3. It does not liberate any ozone or nitrous products: it does not need any gas or ether, such as certain spark gaps require.

4. The oscillations are sustained, and are not composed of trains of waves more or less spaced: the patient does not feel the least faradic sensation, and this is not the case with some of the diathermy machines that are fitted with spark gaps.

The conduction of H.F. currents is a far more complex problem than the conduction of the constant current, or of interrupted currents of low frequency. With metal conductors, whether in the form of sheets, rods, or tubes, the H.F. currents are conducted solely on the surface, and there is no penetration below the surface: this is known as 'the skin effect'. In the case of electrolytes, the H.F. currents penetrate beneath the surface and through the conducting media. This is observed clearly in the application of H.F. currents to the human body.

The conduction of H.F. currents in electrolytes appears to be governed partly by the resistance encountered, and partly by the impedance which these currents set up in their passage. This impedance depends upon the capacity of the conducting medium, the self-inductance that is set up in it, and the frequency of the oscillations.

It is very difficult to determine how far the passage of H.F. currents is influenced by the resistance of the patient's circuit, and how far it is governed by the impedance that it occasions. For the capacity of a condenser with such an imperfect dielectric, as the body furnishes, is extremely small when currents of very high frequency are applied, and the resistance of the tissues varies also with a variation in the frequency.

It is in consequence of this factor of impedance that the H.F. currents do not comply with Joule's law.

A very important paper on this subject by Professor Bordier appears in the *Archives d'Électricité Médicale* (October, 1927) under the title, 'The diathermic heat is not governed by Joule's law. The heating of the medium

traversed is in disagreement with the reading of the milliamperemeter.' Bordier's observations are based largely upon the investigations of D'Arsonval, some of whose experiments are quoted from Bordier's paper.

In experimenting in a small glass vessel with 14 solutions of salt with resistances varying from 13 to 35,000 ohms, D'Arsonval obtained the following variations in the heating effect:

| *Resistance.* | *Heating.* | *Resistance.* | *Heating.* |
|---|---|---|---|
| 13 ohms. | 2 degs. | 1,500 ohms. | 96 degs. |
| 115 | 10 | 2,500 | 80 |
| 180 | 19 | 8,000 | 16 |
| 360 | 50 | 11,000 | 10 |
| 500 | 60 | 22,000 | 4 |
| 730 | 80 | 30,000 | 3 |
| 1,200 | 90 | 35,000 | 2 |

The above experiments were performed with the same intensity of current and for the same time.

It will be noticed that, at the start, the heat increased as the resistance increased, in accordance with Joule's law. Then a maximum value was reached, after which, although the resistance of the solution continued to be increased, the degree of heat declined; until, at the end of the experiment, when the resistance had reached 35,000 ohms, the heating was no more than it had been at the commencement, when the resistance was only 13 ohms.

Experiments with a variety of electrolytes, such as drinking water, horse serum, urine, and colloidal solutions, yielded results of a similar character.

It was found that the more complex the constitution of the electrolyte, the lower was the maximum of temperature reached:

| | | |
|---|---|---|
| Sodium chloride solution . . . | 96 degs. | (1,500 ohms). |
| Drinking water . . . . . | 88 | (800 ohms). |
| Horse serum . . . . . | 84 | (1,150 ohms). |
| Urine . . . . . | 82 | (450 ohms). |

As the result of these experiments, D'Arsonval came to the conclusion that 'the plates (*plaques*) of the vessel and

the liquid interposed between the electrodes constitute not only a resistance, but also a condenser which heats up in accordance with the phenomena of hysteresis or of the dielectric viscosity at these high frequencies'.

Bordier points out that with the living tissues the problem is even more complex, and he comes to the conclusion that 'as is the case with the electrolytes and the colloidal solutions, the living tissues placed between the metal electrodes attached to the terminals of the diathermy apparatus constitute a condenser of variable leakage, which is traversed (1) by a current of conduction, (2) by a current of capacity, by which the effects may be increased or suppressed according to the cases'. Bordier concludes his paper by quoting a mathematical calculation by M. Ch. Fabry which gives results in confirmation of D'Arsonval's experiments.(2)

The conclusion at which Bordier arrives is in complete accordance with the everyday experience of those administering H.F. currents.

The skin is clearly a leaking dielectric with a dielectric value that is constantly varying according to the method by which we apply our treatments. In the case of condenser couch treatments, the patient's skin, his clothes, and the ebonite of the couch form a dielectric with little if any leakage. When we apply bare electrodes directly to the patient's skin the dielectric value of the skin must be relatively higher than when we interpose pads soaked in salt and water between the electrode and the skin. Yet the amount of current registered by the amperemeter and the heating effect experienced by the patient is nearly the same in the two cases.

The phenomenon of the leaking condenser may be actually seen taking place when corns or warts are under treatment by the author's method of indirect diathermy. In this form of treatment the patient lies on a condenser couch connected with one terminal of the diathermy apparatus, and holding two handles connected with the other terminal, a pointed metal instrument is held in the

hand of the operator and applied to the surface of the corn or wart. A small point of bright light, like a minute glow lamp, quickly appears on the under surface of the wart or corn. This light is due to a leaking condenser effect taking place through the imperfect dielectric of the thickened epidermis. The dielectric effect of such a wart or corn must be greater than that of the normal skin.

The mutual relation or reciprocal variation between these two factors, resistance and impedance, must be continually changing: for not only are they mutually affected by the condition of the skin, but also by the situation of the pads. The extent to which they must each respectively govern the passage of the current is entirely different when the current is applied transversely through the thigh, and when it is applied longitudinally through the limb from the sole of the foot to the hip joint.

Perhaps the most striking of all the phenomena attending the administration of the H.F. currents is the absence of muscular contraction and of any sensation apart from that of heat. This absence of excitation is due to the very rapid alternation or reversal of the current, in consequence of which each pole changes from negative to positive, or vice versa, a million times or more a second. In the brief interval during which either pole is negative, there is no time for an effective hydrogen ion concentration to occur before the current is reversed and the negative pole becomes the positive one.

If this theory is correct, namely, that the absence of muscular contraction and sensation is due to the high frequency of the reversals, and not to the frequency of the interruptions: then, on rectifying the current, and so retaining the frequency of interruption but suppressing the reversals, muscular contraction should occur with very small currents, owing to the high density attending so rapid a make and break. This is demonstrated to be the case from the experiments of Cluzet and Chevalier.

### Rectified High-frequency Currents

A most interesting paper by MM. J. Cluzet and J. Chevalier recently appeared on the action of rectified high-frequency currents.(3) Two methods of rectification by means of radio transmitting valves were employed. Four valves were arranged, in the one case in series, in the other in the form of the Wheatstone bridge. In the former case the rectification took the form of merely suppressing one half phase of the oscillations, in the latter the whole of the oscillations were truly rectified into unidirectional oscillations. The physiological effects were found to be identical in the two cases, consequently the more simple method of arranging the valves in series was adopted in the authors' experiments.

These rectified H.F. currents are capable of being measured by a D'Arsonval galvanometer, of producing electrolysis, of charging condensers, and of exciting an X-ray tube. The authors found that, in the process of rectification, there was practically no loss of voltage whether measured across an open arc or through the closed circuit of the patient.

Experiments were conducted at a relatively low voltage by employing a diathermy apparatus, at a higher voltage by the use of a powerful X-ray coil to step up the primary voltage, and at a still higher voltage by the addition of an Oudin resonator.

A very strong tetanization is obtained from these rectified H.F. currents, but it is not painful, and it is stated that it can be continued for more than ten minutes without fatiguing the muscles.

The motor and sensory effects vary with the voltage; when employing the high voltage from the Oudin resonator a contraction was excited with 0·2 m.a., as strong as that obtained with 2 m.a. from the lower voltage of the diathermy machine.

In experiments conducted on the sciatic nerve of a

guinea-pig four hours after death, the following results were obtained:

Faradic inexcitability. Galvanism 10 m.a. H.F.R. (H.T.) 0·5 m.a. H.F.R. (L.T.) 2 m.a.

In cases of peripheral nerve paralysis, the following results were obtained:

(1) Inexcitable to a galvanic current of 15 m.a.
A definite reaction with 0·75 m.a. H.F.R. (H.T.).
(2) Inexcitable to galvanism.
A very definite reaction with H.F.R. (H.T.) 0·6 m.a.

In one case, however, that of a very old infantile paralysis, the patient failed to respond to H.F.R. (H.T.); there was also no response to any other form of stimulation. In these cases when employing H.F.R. (L.T.) ten times the strength of current was required to excite a contraction.

These results are in full accordance with the views on ionic concentration expounded above, for the results are such as might have been foretold by the application of the theory. That is to say, with a sufficiently high voltage and a sufficiently rapid make and break the density of ionic concentration is so high that a muscular contraction can be excited with the minimum of current.

Definite proof is, moreover, yielded by these crucial experiments that the failure of the ordinary H.F. currents to excite muscular contraction is not the result of the frequency of the interruption, but of the rapidity of the reversals, which does not permit of the chemical action of one phase of the current before it is neutralized by the opposite phase.

There is, indeed, only one result from these experiments that we should not have anticipated, namely, the little muscular fatigue induced by ten minutes' tetanization at this frequency. If this absence of fatigue is absolute, and is not attributable to the endurance and enthusiasm of the investigators, it can only be explained on the ground that with very high frequencies the variation in muscle-

tension, which must occur at each stimulus, however frequent, is so slight that its effect in producing fatigue is negligible.

These experiments were conducted with H.F.-damped oscillations; it would be very interesting to know whether identical results would be obtained from the undamped continuous oscillations of H.F. It is possible that the 'period of silence' between each series of damped oscillations has some effect that would be absent when undamped oscillations were employed.

A modern diathermy apparatus, with an oscillation frequency of one or two millions a second, enables currents of 3 amperes or more to be driven through the tissues of the body without producing any muscular contraction or tremor, and with no other sensation than that of heat. The frictional heat generated by millions of ions oscillating in this manner throughout the tissues is very considerable; and by its means the temperature of a whole limb, or of any organ of the body, may be raised to a considerable extent; or the temperature of the whole body may be appreciably increased in the same manner. And, since the heat is generated within the tissues, the effect is incomparably greater than can be obtained by such means as hot baths or radiant heat, which merely heat the surface of the body.

The rapidity with which the heat-regulating mechanism of the organism acts is well illustrated by the experiments of Fürstenburg and Schemel (4) at the Brieger Institute. It was found, in these experiments on the diathermic heating of the stomach, that the temperature of that organ was not increased in proportion to the intensity of current employed. With a current of 300 milliamperes its temperature was raised about half a degree above normal. On increasing the current strength, however, to 3,000 milliamperes, the temperature of the stomach fell to only one-third of a degree above normal.

In agreement with the above results, I have found that, when passing a current of $2\frac{1}{2}$ to 3 amperes through the

body, after about ten minutes' treatment the temperature in the mouth rises about a degree, and is accompanied by a slight acceleration of the pulse rate: this rise, however, both in the temperature and the pulse rate declines again to normal after about ten minutes' further treatment, and then remains at normal, although a current of 3 amperes may be continuously administered for an hour.

Schittenhelm (5), employing the enormous current of 17 amperes, succeeded in raising the temperature of a healthy man 2 to 4 degrees centigrade in one and a half minutes, after which time dilatation of superficial vessels and sweating occurred, and no further rise of temperature could be induced. Prolonging the treatment considerably caused a fatigue of the peripheral vessels and a diminution in the secretion of sweat. Stein (6) also records that the temperature of the body can be raised about 5 degrees in ten minutes.

The employment of the high intensities of current necessary for the production of such rises of temperature has not as yet been generally adopted in electrotherapy, and its adoption would not be unattended with risk.

Although the general rise of temperature in clinical diathermy is a small one, the therapeutic effect on the body as a whole, especially if the treatment be a prolonged one, is not necessarily of little value. The dilatation of the peripheral vessels, the increased perspiration—a very varying factor in my experience—the increased elimination of solids in the urine, and the other results which follow from a rise in the temperature, may be reasonably supposed to aid in the elimination of toxins and to have a favourable influence on the treatment.

When we turn to the local effects of diathermy, the results are far more definite and less hypothetical. By means of the diathermic current, the heart, the lungs, the kidneys, the ureters, the bladder, the ovaries, every organ of the body, or a limb throughout its whole length, may be greatly heated.

The effect of the heat generated within the tissues is to

dilate the blood vessels, thus relaxing spasm and tension and consequently relieving pain.

This relief of pain constitutes by far the most valuable property of the diathermic currents. Occasionally a temporary increase of pain may be experienced during the administration of the current; this is especially found to occur when the current is applied too strongly at first; it would appear to be due to a temporary congestion of the tissues arising from the increased blood supply before the surrounding parts have been relaxed by the heat. This exacerbation of pain is only temporary and immediately ceases when the current is reduced in strength or is cut off; it is usually of good omen, for the subsequent relief is generally very marked in these cases. As a few instances of the effect of the treatment in the relief of pain we may quote the following. Dysmenorrhoea may often be prevented by the application of the current to the ovarian region two or three days before the expected period, or the pain may be immediately relieved during the period by a similar application. A current of about 3 amperes is passed through the abdomen in the ovarian region for about fifteen minutes, and little or no exposure of the patient is necessitated. A renal calculus, from the irritation that it excites, may be gripped by the spasmodic contracture of the ureter, so that its passage is arrested, and a dull aching pain is thus set up: this spasm may be relieved by diathermy, and the passage of the calculus will be facilitated, but then the acute pain of ureteric colic will temporarily replace the dull ache. I once had, in the course of my private practice, a very striking example of this relaxation of spasm following the administration of diathermy.

A patient came to me complaining of lumbago; the pain was of a constant, dull, aching character deeply situated in the lumbar region. I administered diathermy through the back and abdomen for thirty minutes, and the patient left my house free from pain. About twenty minutes afterwards, I was summoned to his residence, where I

found him writhing with pain, and exhibiting the other symptoms of renal colic. He subsequently passed a renal calculus per urethram. In this case, the calculus appears to have been gripped by a spasm of the ureter, and, on the relaxation of this spasm following the application of diathermy, the calculus appears to have set up acute colic on its passage down the ureter to the bladder. The acute pain of neuritis, lumbago, &c., can usually be immediately relieved, and often speedily cured by diathermy applied in the proper manner. Contrasting its action in such cases with the action of the continuous current, my experience is that diathermy should be selected in recent and acute cases: but that in chronic and in less acute cases the continuous current is to be preferred. In many cases the two treatments may be advantageously combined.

The degree to which the tissues are heated depends not only on the intensity of the current but also on the part of the body to which it is applied and on the direction which it takes.

The heating effect will be different when the electrodes are applied transversely and when they are applied in a longitudinal direction along a limb. The heating effect will again be different if the current passes through a fleshy part or through the bony part of a joint.

When the current is applied transversely through a limb or the trunk, the blood continually passing across the path of the current conveys a considerable portion of the heat to other parts of the body, and so tends to cool down the area treated. When the electrodes are so placed, the skin heats up more than the deeper structures, and so affords a satisfactory guide to the amount of current that can be safely applied. When the current is directed along the length of a limb, a column of blood is longitudinally heated, and the heat is not conveyed away by the blood to the same extent as when the limb is transversely heated. In the case of the longitudinal application of the current, the areas of the narrowest cross-section, such as

the wrists and the ankles, will be most heated; for in these parts the density of the currents will be greatest, and very little heat will be experienced on the palms of the hands or the soles of the feet. In such applications it should be remembered that excessive heat in the deeper structures is not felt as heat, but as cramp or pain, and the current should be immediately cut off when any aching, cramp, or pain is excited in the arms or calves during the application of the longitudinal currents. In consequence of these effects, the current must be administered with the greatest care and caution when there is partial stasis, such as accompanies 'white leg' and other similar conditions.

Great care is also needed, even in the transverse application of the current, when there is much oedema or when the circulation is otherwise impeded.

Owing to the effect of diathermy in lowering blood pressure, special care is necessary in its administration to exhausted patients with low blood pressure: and even more caution is necessary, in this respect, in regard to those patients who have been overtired and exhausted by a sudden and temporary shock or strain, than in regard to those who have become gradually and slowly exhausted by a long illness.

The increased local blood supply that results from diathermy contra-indicates the application of this treatment to any organ or part of the body from which haemorrhage may be feared. The application of diathermy is, therefore, contra-indicated through the lungs or through the stomach, when there may be reason to fear haemoptysis in the one case, or haematemesis in the other.

Although the therapeutic effects of high-frequency currents may be mainly due to their thermal action, there are good reasons for thinking that the vibrations set up by the high-frequency oscillations of the tissue ions may have an important therapeutic effect apart from this heating action.

In the application of these currents we frequently encounter effects that it is difficult to explain solely as the

result of this thermal action. Take, for instance, the almost complete removal of discoloration from a bruised surface after the transverse application for twenty minutes of the H.F. current. If the active electrode covers only a portion of the bruise, it will be found that the ecchymosis is only removed from this area and that the outline of the remaining bruise is sharply defined and corresponds with the shape of the electrode. The bruising is, moreover, more readily removed by H.F. currents of tension than by those of quantity. If the disappearance of the discoloration were solely due to an increased local circulation consequent upon the heating action of the current, we should expect to find the margin less well defined.

Again, it is difficult to explain the almost complete disappearance of effusion and swelling that follows the transverse application of H.F. currents to a recent Colles' fracture, on the ground of heat generation alone. The superior results in the treatment of high blood pressure that many observers have commented on, obtained by the application of H.F. currents of tension rather than those of quantity, point to the action of some agent other than heat alone. What we are accustomed to term the 'decompressor action' of diathermy is more readily visualized as a direct vibratory action than as a heat effect.

The remarkable phenomena, which were obtained by Professor R. W. Wood and A. L. Loomis (7) when experimenting with sound waves of high frequency and great intensity generated by a piezo-electric oscillator of quartz, afford a very striking example of the extraordinarily powerful 'pounding' action of supersonic vibrations generated by a H.F. apparatus.

The apparatus employed in these experiments was a very powerful one, 50,000 volts with a vibration rate of 300,000 a second. It resembled in general outline a diathermy apparatus of the triode valve type. One terminal of the apparatus was connected with an electrode formed by a plate of lead, supporting several discs of

quartz on which was placed a thin sheet of brass connected with the other terminal of the apparatus, the electrodes and quartz being immersed in a bath of transformer oil.

The following were among the results obtained: 'Though the mercury registered only 25 degrees, the thermometer became so hot at the point where it was held between the thumb and finger that it had to be released. The heat, of course, is developed by friction between the vibrating glass stem and the skin of the fingers, or rather by the rapid *pounding* of the transverse vibrations, and becomes unbearable only when the glass is squeezed tightly between the thumb and finger.' Blood blisters persisting for several weeks were formed as the result of dipping a fine glass rod in the bath. Small fish and frogs were killed by submitting them for one or two minutes to the vibrations. 'Filaments of living spirogyra were torn to pieces and the cells ruptured.' 'Red blood corpuscles in physiological salt solution are rapidly destroyed, the turbid liquor becoming as clear as a solution of a red aniline dye.'

The conditions under which these experiments were performed obviously differ too much from those under which diathermy is administered to allow of any conclusions to be drawn from them as to the physical action of H.F. currents within the body. They, however, serve to illustrate how the H.F. currents may be utilized to furnish 'pounding', dispersive, and disruptive effects. Perhaps, in a much modified form, a therapeutic action may be found for these supersonic vibrations.

Dr. J. E. G. Waddington, of Detroit, has carefully investigated this problem of the action of H.F. currents apart from their heating effects. In an exhaustive paper on the subject (8) he quotes some important experiments by Professor D'Arsonval in collaboration with Dr. Charrin (9). 'We have submitted a very active diphtheria toxin to the action of a H.F. current for a quarter of an hour. We have then injected two and a half cubic centimetres into three guinea-pigs, and the same dose, but unelectrified, into three controls. The three controls were

dead within twenty-six hours. The three others were living seven days after their injection and were then injected with half a cubic centimetre of very active diphtheria culture. Three controls, similarly injected, were dead within three days. Of the three others, one died on the fourth day, but the other two were in good health seven days after the injection.'

To the objection that the bactericidal effect was the result of the heat generated by the H.F. current, D'Arsonval replied: 'this objection has no value whatsoever, for in the experiments never did the temperature in the media or produced within the animals ever exceed 98·5° F'.

Nagelschmidt, although he is of opinion that 'tension does not play any role in the therapeutic action of H.F. currents', nevertheless states, 'I do not believe that the action of diathermy is only derived from the thermal effect, though that is the most important factor. It is very likely that high-frequency oscillations produce intra-atomic changes like other ether waves.' (Waddington.)

This subject has not hitherto received the attention that it deserves, and further experimental investigation is needed before we can differentiate with any degree of exactitude between the thermal and the other therapeutic action of the H.F. currents.

In France the recent introduction of the triode valve apparatus with its undamped continuous oscillations has naturally given rise to a comparison between the action of this type of machine and the action of the spark gap type with its slightly damped oscillations.

Lemariée (10) in a recent thesis reported twenty-eight gynaecological cases successfully treated by the undamped oscillations. He proclaims the superiority of the triode valve apparatus over the spark gap type, and denies that any advantage can be obtained from the faradic effect.

Dénier, on the other hand, in a paper read before the Société Française d'Électrothérapie, May 1927, made a comparative study of the results obtained from two

types of apparatus yielding damped oscillations. In one of these machines the frequency was insufficient entirely to damp out the faradic effect; in the other the frequency was so high that the faradic effect was entirely abolished. In the three cases upon which his thesis was based, the predominant symptoms were spasm and pain. These symptoms resisted the application of the very high frequency, but yielded to the frequency which was not sufficiently high to abolish entirely the faradic effect.

D'Arsonval in his last communication to the French Academy of Science expressed the opinion that the continuous oscillations should be employed when a thermic effect is especially indicated, reserving the damped oscillations for cases in which an action on the sympathetic or glandular systems may be required.

**Summary and Conclusions.**

High frequency currents are divisible into two categories: H.F. of tension, and H.F. of quantity. For the former an instrument yielding a current of higher voltage and lower frequency is the more suitable: for the latter the triode valve apparatus is preferable.

High frequency currents fail to excite muscular contraction, or sensory or chemical phenomena, not on account of the high frequency of the interruption of the current, but owing to the rapid reversal of its polarity.

The thermal effects of H.F. currents are preceded by a vibratory action which produces valuable therapeutic effects distinct from the consecutive heating action of these vibrations.

The condenser or leaky condenser effects only appear when H.F. currents encounter very high resistance; consequently it is only in the passage of H.F. currents through the epidermis that, in clinical practice, the variation to Joule's law need be considered. Within the skin surface the H.F. currents, owing to the low resistance of the electrolyte of the tissues, pass by conduction and consequently conform to Joule's law. The practical application of this

point is further considered in the chapter on 'Practical Hints and Methods' in relation to its bearing on the question of the employment of dry or wet electrodes.

### Surgical Diathermy.

The surgical application of diathermy is useful in a variety of conditions: it affords the following advantages compared with the Pacquelin or the electric cautery.

The active electrode of the diathermy apparatus is not itself heated by the passage of the current, and only acquires a slight warmth by convection from the heated tissues. The tissues are coagulated and are not charred and incinerated as when the actual cautery is applied, and consequently there are no charred tissues to adhere to the instrument and set up bleeding when they are removed together with the instrument to which they are adherent. This oozing of blood consequent upon the removal of the heated instrument is often the source of much inconvenience when the actual cautery is employed.

Diathermic coagulation is a process of auto-sterilization, as any organisms which may be present in the effective path of the current are destroyed by the heat generated. No shock accompanies or follows its application.

Provided that care is taken to avoid its application over areas in which large blood-vessels are situated, there is no risk of primary or secondary haemorrhage: and provided that similar caution is exercised in avoiding the neighbourhood of nerves and important structures, the risks attending the administration of surgical diathermy are very small.

When applying this treatment to an area in which important nerves or vessels are situated, the depth to which the heating action takes place may be definitely limited by the employment of the bipolar method, utilizing electrodes with multiple points; by inserting these spikes to the depth to which it is desired to limit the action of the treatment, all danger of injuring subjacent structures can be avoided.

There exists at the present time rather a multiplicity of methods for the application of surgical diathermy. They may, however, be classified into three main divisions:

1. Diathermic coagulation.
2. Fulguration, or the arc methods.
3. Indirect surgical diathermy.

### 1. Diathermic coagulation

Diathermic coagulation may be employed either by the monopolar or the bipolar method. In the monopolar method the patient may either lie on a condenser couch (a couch on which an overlapping sheet of ebonite is superimposed on one or more plates of zinc which are attached to one of the terminals of the apparatus); or the indifferent electrode may consist of a large metal plate secured to a suitable part of the patient. The active electrode, in the form of a small metal disc or point, is applied to the part to be destroyed, the current is turned on by a foot switch, and is interrupted when the required depth of coagulation has been achieved. The tissues are coagulated by this method in the form of a cone, the apex of which is at the point of application of the active electrode. At this point the heat destruction is most complete, but it extends towards the indifferent electrode in a widening area and to a diminishing degree as its density becomes less. The depth to which the coagulation occurs depends on the strength of the current and the length of time for which it is applied.

The bipolar method consists in the employment of two active electrodes formed either by two flat discs, or two small plates from which project multiple points. When employing the discs a superficial area of coagulation is obtained, extending between the electrodes, and usually deepest at its central point.

Generally the better way to apply this method is by means of spiked electrodes. These are best formed by six or eight needles soldered into a metal base. The electrodes so formed are employed in the manner described above.

**2. Fulguration. The Arc operation. The endotherm knife.**

Fulguration by long sparks has been employed for the destruction of small growths since Oudin described the production of these sparks from his resonator in a paper that he communicated to the 'Bulletin de la Société de Dermatologie', August 3, 1894. The application of these long sparks has been found to be too inexact, too painful, and too superficial in their effects, to lead to their general adoption.

During the past few years, a method involving the employment of an arc of minute length obtained from a three electrode valve apparatus, or from a certain type of spark gap machine, has come into use in America, Germany, and this country.

This method is a monopolar one, the active electrode consisting of a needle or a very thin flat blade. When, with the current previously switched on, the blade or needle is brought nearly into contact with the tissues, a minute arc is formed: the knife or needle is then plunged into the tissues and drawn through them in the manner of making an incision.

The instrument must be kept constantly in motion and it will be found that it meets with scarcely any resistance as it sears or cleaves its way through the tissues; it is said to pass through them as though they were composed of butter. Only a thin film of coagulation is formed, but this effectively seals the lymphatics and small blood-vessels.

If the operation is properly performed, the divided edges may be sutured and healing by first intention will ensue. If, however, the needle is not kept constantly in motion, charring of the tissues by the sparks will occur, and primary union will be thus interfered with. Malignant breasts have been excised and other operations of an extensive character have been performed successfully by this method.

A general anaesthetic is needed, and the operative procedure involved renders the practice of this method one for the surgeon rather than for the electrotherapist.

**Indirect Surgical Diathermy.**

Minor blemishes of the skin, such as warts, moles, superficial naevi, &c., also small haemorrhoids, or rodent ulcers, may be removed almost painlessly, and with great accuracy and delicacy by this method, which was introduced by the author some years ago.(11) The patient, when undergoing this treatment, lies upon a condenser couch, the metal plates of which are connected with one terminal of the apparatus, and holds in his hands two electrodes connected with the other terminal: in this manner he is charged with about 500 milliamperes, the actual amount of the current employed in the operation being previously registered on the milliamperemeter. A pointed metal instrument, with no wires attached to it, is held in the hand of the operator and applied to the part to be destroyed. The current with which the patient is charged is attracted to the base of the growth, and inductively attracts to its surface a current of opposite polarity but of similar intensity from the capacity of the operator. The current oscillates in this manner with a similar frequency to that of the instrument employed, so that the destructive process operates almost simultaneously on the surface and the base of the growth.

In treating corns and warts in this manner, the thickened cuticle is not destroyed, and serves as a protective covering to the underlying parts that have been subcutaneously destroyed, until these parts are at the end of ten or fourteen days completely healed, and then the thickened cuticle separates off.

This procedure is not suitable for the treatment of large growths, as its action is only superficial: it is, however, in the everyday practice of the electrotherapist, the most generally called-for of all the destructive diathermy methods.

Bordier (12), who has aptly conferred upon the method

the name of 'Coagulation diathermique sans fil' (D.S.F.), states that it is much less painful than the same operation performed by the usual direct methods, and that it does not call for the administration of an anaesthetic.

It is especially useful in delicate operations, such as the removal of a superficial naevus from the eyelid. Usually it is best to apply the point of the needle in actual contact with the part to be treated, but in some cases it is better to hold the point a short distance away, and so utilize short sparks. It may also be employed in the form of the cutting arc.

A slight modification of this process admits of the administration of 'diathermic massage'; when applying it in this manner the tips of the operator's fingers are substituted for the metal instrument, and there is consequently not the same degree of concentration of current and heat. By gently stroking a painful superficial area in this way a sensation of warmth is imparted to the part, which is very soothing and has been found to be of considerable benefit in the treatment of acute facial neuralgia.

In addition to the above methods, diathermy may be applied in conjunction with the cystoscope for the destruction of small tumours within the bladder: this is a method, however, that should be only used by those who are skilled in the use of the cystoscope.

The administration of diathermy, both in its medical and surgical forms, requires more skill and experience than any other form of electrical treatment.

In the application of medical diathermy, the position of the pads and the direction of the current are of the greatest importance. In brachial neuritis, for instance, the seat of the trouble is, in my experience, most commonly situated where the nerves pass through the intervertebral foramina of the cervical spine: and, in such a case, to apply the pads to the points to which the pain is referred would be an utterly useless procedure. Again, when the current, as is often the case, has to be pushed to nearly the limits of safety, its administration should

certainly not be entrusted to the hands of unqualified persons. One of the fascinations to the experienced electrotherapist of this form of treatment is the frequent discovery of new methods of its application.

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# CHAPTER V

# THE INFLUENCE MACHINE AND STATIC ELECTRICITY

**The Therapeutic Action of the Currents derived therefrom**

THE frictional machines employed in the eighteenth century for generating static electricity proved unsatisfactory in consequence of their small output, their susceptibility to the dampness of the atmosphere, and the attention which their rubbers required; they have consequently been entirely superseded in therapeutic work by the influence machine.

The principle of the influence machine was first demonstrated by Volta, in 1775, by means of his electrophorus. In order to understand the action of an influence machine it is best to make a preliminary study of this simple apparatus.

The electrophorus (Fig. 12) consists of a metal base A, containing a flat circular disc B, composed of resin, sulphur, ebonite, or other non-conducting material, and a circular metal disc C, attached to an insulated handle of glass or vulcanite D.

When the resin disc B is rubbed with cat's fur, it becomes charged with negative electricity on its surface. The metal disc C, when applied to the resin, becomes inductively acted upon by the negative charge on the surface of the resin, with the result that the electrons, or negative charge of the metal disc, are repelled to its upper surface, while a positive charge remains on its surface in contact with the resin. On touching the upper surface of the metal disc with the finger, the electrons which have been repelled to its surface are discharged to earth, and the disk C then becomes positively charged.

A Leyden jar or other capacity can be then charged positively by contact with the metal disc, and the disc can be recharged repeatedly by again bringing it into

contact with the resin and retouching it with the finger; this process can be repeated indefinitely without recharging the resin, provided that the atmosphere is sufficiently dry and free from dust to prevent the initial charge from leaking away.

The influence machine mechanically performs the function of the electrophorus. The first type of this apparatus was introduced by C. F. Varley in 1860. Five years later it was followed by the machines of Holtz and Toepler, and more recently these machines were displaced in general use by the well-known Wimshurst machines.

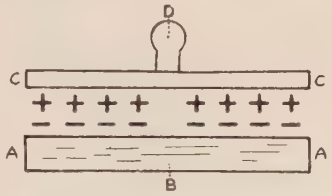

FIG. 12. The electrophorus.

The Wimshurst machines are of two types: one type is provided with sectors of tinfoil near its circumference, and is self-exciting; the other type has no sectors, and has to be excited by friction from the finger or other source, or by receiving a charge from another machine.

For medical purposes the sectorless type is preferable, as it is less likely to reverse the polarity of its collecting brushes whilst it is in operation. A Wimshurst machine consists of 2, 4, 6, or more discs of glass, or ebonite, arranged in pairs. In each pair one disc revolves clockwise, the other in the opposite direction. Its mode of operation may be explained as follows:

Let the anterior and posterior disc of the ordinary Wimshurst be represented for simplicity of explanation by an external and an internal cylinder respectively (Fig. 13). On applying a dry finger in contact with the external ebonite cylinder at A, opposite the brush B, a positive charge is excited in the external cylinder at the point of contact. The finger may then be taken away: by the inductive action of this positive charge, a negative charge is excited in the brush B, which is in contact with the internal cylinder and conveys to it this negative charge.

The internal cylinder revolving in an anti-clockwise direction brings this negative charge towards the brush C, in contact with the external cylinder; on arriving at this point the negative charge on the internal cylinder induces a positive charge in the brush C, which is communicated to the external cylinder in contact with it, and is carried by the external cylinder, revolving in a clockwise direc-

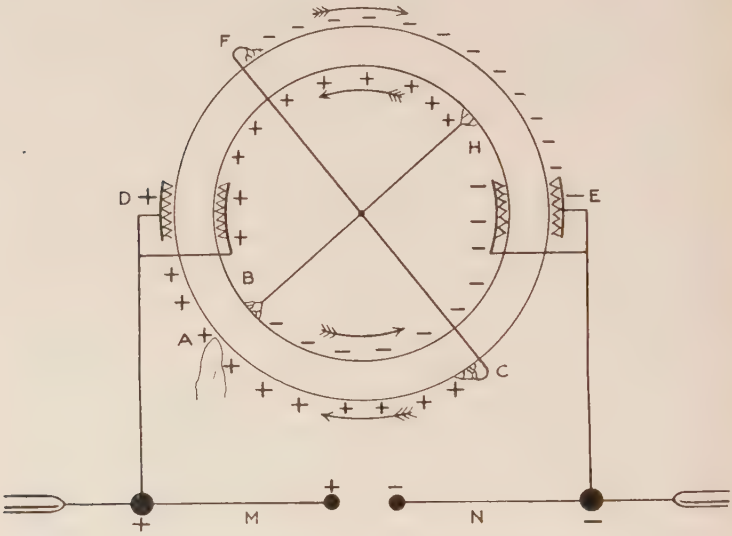


FIG. 13. Diagram to illustrate action of an influence machine.

tion, to the collecting combs D. The internal cylinder, continuing its rotation, brings its negative charge to the collecting combs E. The upper halves of the plates receive a charge of opposite polarity to their lower halves in the following manner. When the brush C receives its positive charge, a negative charge is repelled along the metal rod CF to the brush F, which thus becomes negatively charged and imparts a charge of similar polarity to the portion of the outer plate in contact with it. This negative charge is then conveyed to the collecting combs E.

In a similar manner, the brush B having a negative

charge, a positive charge will be repelled along the rod BH and will collect on the brush H, from which it will be communicated to the part of the internal cylinder in contact with it, and will thence be conveyed to the collecting combs D. Thus the combs D will collect the positive electricity from the upper halves of the internal and from the lower halves of the external cylinders; whilst the collecting combs E will collect the negative electricity from the upper halves of the external and the lower halves of the internal cylinders. These respective charges will be conveyed to the discharging rods M and N.

### On the Choice of a Static Machine

The following are the requirements of a good static machine:

1. The machine should not require too great a force to drive it. This point is not of so much importance as formerly, when the machine was driven by hand. Nowadays, no electrotherapist would contemplate driving the machine otherwise than by mechanical or electrical power, and the power of the driving motor can be easily regulated to meet the requirements of the apparatus.

2. The machine should be as little as possible affected by damp and weather conditions, so that it may be readily excited and yield its maximum output at all times. This is a self-evident proposition which it is easier to lay down than to accomplish completely. It is a point which will be dealt with when considering the maintenance of the apparatus.

3. The machine should be capable of yielding a current of very high potential. Provided that the insulating material used is efficient, the potential obtainable depends solely upon the diameter of the plates; the space between the innermost projection of the collecting combs may be regarded as the cross-section of the insulating material. It is evident that a potential cannot be obtained greater than that required to yield a spark across a gap equal to the interval between the innermost projection of the

collecting combs. In actual practice a spark length should be obtainable, under ordinary working conditions, equal to one-third the diameter of the plates.

4. The output in current should be as great as possible, and should admit of ready and exact regulation. The output depends on the number of the plates, their proximity to one another, and the rate at which they revolve. (The output, however, is not in direct proportion to the increase of these factors.) It consequently follows, if a high milliamperage is to be obtained, that the plates should be constructed of a material permitting a high rate of revolution without disintegration occurring under the influence of centrifugal force at high speeds.

The regulation of the output can be effected in two ways, namely, either by adjusting the speed of the motor, or by means of a device for leaking away the current accumulating at the collecting combs, as in the ingenious arrangement fitted to the Baker machines.

5. The polarity of the apparatus should not change during its operation. This is accomplished by keeping the machine as dry as possible, and by avoiding the use of machines furnished with sectors.

6. The apparatus should be robustly constructed in all its parts, and the plates should be of a material which is not liable to warp or deteriorate on exposure to light. The whole apparatus should be enclosed in a dust, and, as far as possible, a damp-proof glass case.

The Wimshurst machine with sectorless plates is chiefly used on the Continent and is highly spoken of by French workers; it has, however, one or two serious faults. It is perhaps due to their use of inefficient machines that the French are unable to claim the same pre-eminence in the use of static electricity that they possess in other forms of electrotherapy. They appear from their writings to under-rate the value of the Morton wave current, the most valuable of the static methods, for the effective administration of which a machine of the American type is indispensable.

Apart from the tendency of the ebonite plates of the Wimshurst machines to warp and get out of truth, they are liable to sulphate when exposed to a bright light, and so lose some of their non-conducting properties, thereby becoming much less efficient. This latter fault can, to a great extent, be remedied by keeping the apparatus covered by a dark cloth when not in use; and the sulphur deposit, when formed, may be removed by rubbing the plates with a solution of ammonia or paraffin. The Wimshurst does not necessarily require a glass case, but such a fitting is of use in keeping dust away.

In actual practice it is the difficulty of obtaining the slow, heavy, pounding spark that renders the Wimshurst unsuitable for the Morton wave current.

To obtain a satisfactory apparatus for all the forms of static treatment, recourse must be made to the American machines. As the result of the work of the late Dr. W. J. Morton, of New York, and in more recent years of the writings of Dr. William Benham Snow, also of New York, static treatment has developed in the United States to a far higher degree of efficiency than in any other country.

In Great Britain, Dr. F. Howard Humphris, who learnt the therapeutic value of the static machine during his residence in America, has succeeded, in spite of much opposition from those who neither possessed nor had used an efficient apparatus, in obtaining for static treatment in this country an established position among the recognized therapeutic methods.

The American machines are of two main types, the Van Houten and Ten Broeck glass plate machine (212 East 23rd Street, New York City), and the Baker static machine manufactured by the Baker Electric Co., 438 Asylum Street, Hartford, Conn. Both these types are of the sectorless variety and have therefore to be provided with small self-exciting machines to impart to them the initial charge. The glass plates of the Van Houten machines cannot be revolved at a high rate of speed; their

milliamperage output is therefore small unless a large number of plates are employed. On the other hand they will run very slowly and will yield the slow, heavy, regular, pounding spark of high voltage, which is so essential for the proper administration of the Morton wave current; these are then the machines *par excellence* for this method. Glass certainly appears to be the best dielectric material for obtaining this high voltage spark at low speed.

In the Baker type of machine * the revolving plates are made of sheets of paper compressed and cemented together under heavy hydraulic pressure. Manufactured in this way they ring like steel when struck, and their cohesion is such that they can be revolved at very high speed without fear of disintegration. The output in milliamperes is very satisfactory, and it can be leaked away, when a smaller output is required, from the collecting combs back to the field combs by a very ingenious arrangement of a lever operated by hand, a patent of the Baker Company. Between the revolving plates are a pair of stationary glass plates, between each pair of which, near their circumference, two strips of tin-foil are diagonally inserted. To one of these strips of tin-foil an initial charge has to be conveyed from an exciting machine before the apparatus will function.

The output of these machines is far greater than that from those furnished with glass plates; they are therefore more suitable for the static charge, static breeze, and vacuum tube treatments. Moreover, with practice the excess of current can be so readily and easily leaked away that they are quite suitable for administering the Morton wave current.

An efficient machine of this type for either hospital or private work is one fitted with eight revolving and eight stationary plates of 36 inches in diameter. This is described as an 8–16 type. I have had two such machines for the past seven years in daily use, one in the hospital,

* This type of static machine is no longer manufactured.

the other in my private practice, with most satisfactory results. The chief drawback to the general adoption of these machines is their high cost; before the war a completely equipped Baker machine, such as is above described, cost £200 delivered and erected in this country. This price would probably be more than trebled at the present time.

### The Care of the Static Machine

To keep a static machine in good working order, the case should be made as closely fitting as possible to exclude dust and damp. Within the case should be placed dishes containing sulphuric acid, or bags containing quicklime. In my own practice I employ three 12 inch by 10 inch photographic developing dishes containing sulphuric acid; and also, within the same case, two boxes constructed of wooden battens, spaced about half an inch apart with lids similarly constructed, the interior of the boxes being lined with a close-mesh gauze to prevent the dispersion of the lime dust. The boxes are one-third filled with about 10 lb. of quicklime. Care must be taken to place only sufficient acid in the dishes to cover the bottom of the vessels to a depth of a quarter or half an inch, or otherwise the acid, as it absorbs the moisture, will in time overflow the dish; in the same way, the lime, if it is too closely packed, will, on absorbing the moisture, swell and burst through the gauze lining of the boxes. An anthracite stove continually burning in the static room materially assists in keeping the machine in good condition.

The static machine should not be placed against or near the wall, nor should any furniture be placed near it. If possible it is a great advantage to place the static machine in a room by itself.

The insulated platform should be strongly constructed of well-seasoned, hard wood; its dimensions should be about 42 inches long and about 26 inches in width; round the edge a rim should be attached to prevent the treatment chair from slipping off, and its corners should

be well rounded. It should be mounted on six vulcanite or glass legs, 4 to 5 inches in circumference and 9 to 10 inches in length. The insulation of the platform is much improved by placing the legs on glass insulators such as are sold for insulating pianos.

At least two Leyden jars should be provided; the inner coatings of these are attached to the discharging rods, and their outer coatings are earthed, or are attached to the patient according to the form of treatment to be administered. It is a good plan to have several Leyden jars of different sizes.

The treatment chair should be constructed of cane, or of well-seasoned wood; it should be free from nails and metal of all kinds. It is difficult to be certain that no nails or small brads have been used in the construction of the cane chairs until a static bath treatment has been given, when the presence of any metal will be readily detected. The back of the chair should be made adjustable, so that it can be raised or lowered, or be entirely removed. A detachable leg piece should be fitted to allow of the chair being used as a couch for vaginal or prostatic treatments.

### The Determination of the Polarity of the Collectors

The positive charge appears on the collecting combs as a number of bright blue points (positive points); if the discharging balls are slightly separated, the sparks will be seen to travel by a nearly straight line for about an inch on the positive side, and they will be of a bright blue colour. If a dry stick is brought near the positively charged rod or ball, only a short stream of sparks will be obtained.

On the negative side of the machine, at the collecting combs, the charge appears as a brush or aigrette; on separating the balls the sparks issuing from the negatively charged ball at once diverge and are of a pale violet colour. From a dry stick approached to the negative side a long aigrette or brush discharge is obtained.

### Connexions to Earth

Two long brass chains should be provided; one of these should be placed on the right and the other on the left of the machine. Each of them should be led to earth by a separate path; one earth connexion may be conveniently made through the water pipes, the other should lead by a wire to a plate buried in the earth. An earth connexion should not be made to, or near to, a gas pipe.

### The Therapeutic Methods obtainable from the Static Machine

The therapeutic effects of static electricity become manifest when the charge ceases to be static and becomes current electricity. To speak of static currents is to make use of a contradiction in terms, for of course when the static charge is converted into a current it ceases to be static electricity or electricity at rest.

The treatments derived from the static machine may be either general or local in their action.

**The Static Charge** (synonyms: Static Insulation, the Static Bath, Simple Charging, Static or General Electrification).

This form of treatment has a general or constitutional effect.

**Arrangement of Apparatus and Patient.** The positive side of the machine is earthed, the discharging balls are widely separated, and the negative side is connected with the platform by means of a hooked brass rod, known as the Shepherd's Crook. The patient is seated on the platform in a reclining chair, and care should be taken to place him in a comfortable position with the limbs relaxed and the head supported by cushions.

**Method of Administration.** The machine, previously charged, should not be started until the patient is comfortably seated. The full output of the apparatus is utilized. The operator should not approach too near the platform, or he will draw sparks from the patient. The

patient should be instructed not to talk, to keep himself as quiet as possible during the treatment, and to compose himself for sleep.

### The Therapeutical Effects of the Static Charge

Let us first note what we observe whilst the patient is undergoing this treatment.

The most obvious phenomenon is that the patient's hair 'stands on end'. This is due to the hair acting as a separate capacity, and, its extremities being free to move,

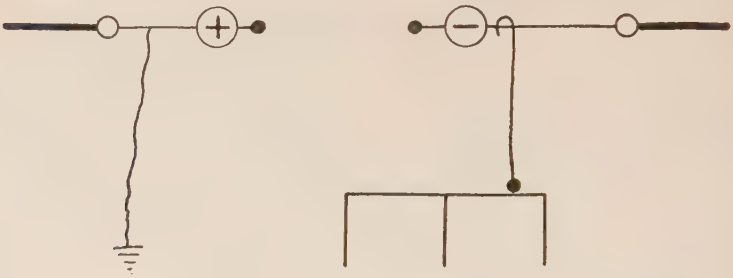

Fig. 14. Diagram of static charge.

it is repelled from the body, which has a similar electrical charge, in accordance with the elementary electrical rule that bodies having a similar electrical charge are repelled from one another. Not only the hairs on the head but all the hairs covering the skin can be seen to be repelled in a similar way. If the patient extends his arm and fingers, the current will be seen leaking away from his fingers in the form of a brush discharge. The patient usually describes his sensations as of a particularly soothing nature, and he will often drop off to sleep, even though the complaint for which he is undergoing treatment may be sleeplessness. A very gentle tingling sensation is experienced, described by some patients as a feeling of being covered with cobwebs.

The explanation of these phenomena is that the patient is charged all over with negative electricity; this charge is inductively attracted to the surface of his body by the

walls, furniture, and other surroundings. The charge is prevented from discharging by the insulating or dielectric action of the air. The patient may therefore be likened to the inner coating of a Leyden jar, of which the air takes the place of the glass dielectric, the walls, furniture, etc. of the room forming its outer coating. The air, however, is not a perfect insulator or dielectric, owing to the dust and moisture which it holds in suspension; consequently a considerable amount of the charge, in the form of current electricity, is continually leaking away from the patient to the neighbouring objects in the room.

It is evident from these phenomena that the skin all over the body is being continually stimulated by the high potential charge, which is either gradually leaking away, or is maintained in a state of electrical tension on the skin surface by neighbouring charges of different polarity, acting inductively through the dielectric of the air.

Renton Elliott (1) has shown that stimulation of afferent nerves leads to an increase in the output of adrenalin from the suprarenal glands, and consequently to an increase in the blood pressure. There is much evidence to show that the raising of the blood pressure, due to the stimulation of the afferent nerves of the skin, is the primary and main effect of the static charge. For instance, it has been recognized for many years that this form of treatment is especially indicated for cases of neurasthenia with low blood pressure, that it is also indicated as a general stimulant or tonic when the patient is exhausted by prolonged pain, anxiety, or overwork, or where sleeplessness has resulted from any of these causes. In short, the treatment holds out hopes of benefit when the symptoms are such as are associated with low blood pressure. On the other hand, its use is contra-indicated when the blood pressure is raised; in fact, it ought never to be applied where there is marked hypertension. I was once treating, for chronic rheumatism of one of his knee joints, an old farmer of the apoplectic appearance usually regarded as typical of the national John Bull and clearly

indicative of arterial hypertension. The joint was improving with galvanism, when one day, on stepping out of his trap, he unfortunately twisted the affected knee, and to remove the resulting effusion I gave him the Static Morton Wave current. He, soon after the commencement of the treatment, began to complain of 'fuzziness' in the head. On his next visit, he brought a message from his wife to the effect that she did not so much mind her husband being 'groggy' in the knees, but she did not want to have him 'cracky' in the head as well, so she would not like him to have any more of the treatment which he had last time. This untoward occurrence was clearly the result of an increased blood pressure, and, being an undesired and unlooked-for effect, was consequently more convincing than scores of successful treatments specially designed to prove the value of some particular method. Bordier (2) records that as the result of the static bath treatment 'the arterial tension is increased, all experimenters are agreed upon that point. An experiment by Charcot clearly showed this effect of the bath; the blood ceasing to escape from a man who was being bled, he was given a charge, when the blood recommenced to flow.'

Bordier also calls attention to the acceleration of the pulse rate, and quotes Truchot (3) to the effect that the acceleration may be as much as 20 per cent. The return to the normal pulse rate is said not to take place till a week has elapsed after the cessation of the treatment. So far as my own observations go, the immediate rise of blood pressure after the treatment is not always very marked; but I have found that a later rise in the arterial tension usually synchronizes with an improvement in the general symptoms.

The following are the other effects claimed from the application of the static charge: a rise in the general temperature of the body, an increase in the excretion of urea, an increase in the dynamo-metric force, and an increase in the secretion of the sweat glands. With the

exception, perhaps, of the last named, which I have usually found to be most noticeable during a first treatment, and which may be reasonably attributed to a fear of the unknown, all these effects can be attributed to an increased blood pressure.

The special indications for this form of treatment are neurasthenia when associated with low arterial tension; sleeplessness, when arising from overwork or worry or other exhausting causes; headaches, when arising from similar causes.

There is a variety of the static charge treatment in which the discharging balls are approximated, and a spark allowed to discharge across them; it is termed 'Potential Alternation', or 'Interrupted Electrification'. It need only be mentioned to be condemned, as it only irritates and disturbs the patient, and can serve no useful purpose.

### The Dosage or Quantity of Electricity administered to the Patient

At first sight the static machine is a most alarming instrument, and the patient, in reply to the question which, at his first visit, he usually asks in reference to the voltage of the apparatus, does not derive much reassurance from the kind of reply often given 'Several hundred thousand volts', or even from the still more inaccurate answer 'A million volts'.

As a matter of fact the static machine is one of the safest instruments in the armamentarium of the electrotherapist. The maximum output from a good French machine is given as from one-tenth to one milliampere, and the maximum output from a modern Baker machine is from one to two milliamperes. As in all other forms of electrical treatment, it is the density of the current administered to the patient that must be considered, and this depends upon

$$\text{Superficial Density} = \frac{\text{Quantity of Electricity}}{\text{Surface}} \text{ or } D = \frac{Q}{S}.$$

Even in a direct short to earth the amount of current passing would be extremely small; but as the patient in all static treatments is placed on an insulated platform (except in the administration of the static induced current, in which case the amount of current which the patient receives is limited by the capacity of the condensers employed), the amount of charge which he can receive is consequently limited by his capacity, which varies with his surface area, and in any case gives rise to a very small amount of current. The result is that the density of the charge on any square centimetre of the patient is extremely small; so minute is it that a new electrical term, the Franklin, has been introduced by Benoist to express it. A franklin equals 1/3,000,000,000 of a coulomb; it is the quantity of electricity which repels with the force of one dyne (about a milligram weight) an equal quantity of electricity of the same polarity at a distance of one centimetre.

Benoist has designed an electrodensimeter, an instrument which registers in franklins the density of the static charge on one superficial square centimetre of the body; in all cases the amount is found to be extremely small, perhaps ten to fifteen franklins. Such calculations show the minuteness of the electrical density of the static charge and serve to explain the absolute safety of this treatment.

### The Static Breeze

If an earthed metallic electrode is brought near a patient receiving a static charge on the insulated platform, the patient's charge will immediately discharge to earth in a powerful disruptive spark; this is known as the static spark, and will be described later. If, however, in place of a good conductor, a dry stick or other body of high electrical resistance is used, the charge will pass gradually to the conductor from the patient in the form of a convective brush or breeze; this is known as the static breeze. If the patient has a positive charge, the breeze will only

be an inch or two in length, and will be very prickly or stinging in character. With a negatively charged patient, and this is the polarity used in this treatment, the discharge will be in the form of a bluish brush, and by using a suitable instrument a breeze 12 inches in length may be readily obtained. Various forms of electrodes have been designed for this purpose; a well-seasoned ash walking-stick answers very well, but for a smooth convective brush discharge the best instrument is the De Kraft pencil.

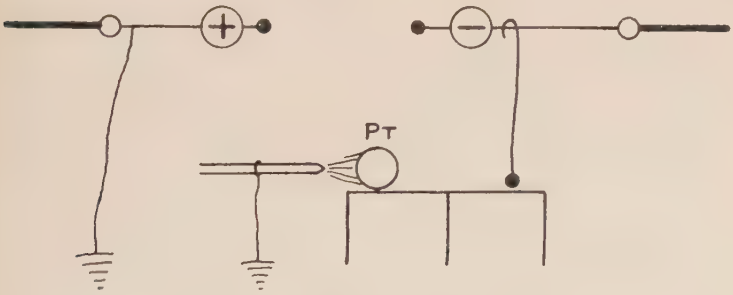


FIG. 15. Diagram of static breeze.

This consists of a vulcanite fibre tube about 18 inches long and three-quarters of an inch in diameter, tightly packed with asbestos string or powder, and terminating at the extremity towards the patient in a blunt brass point with an angle of about 90 degrees; the other end of the instrument is fitted with a brass cap and ring for attachment to the grounding chain. An instrument constructed in this way gives a very soft discharge, which when the rod is held some distance from the patient gives him the sensation of a cool breeze; if the instrument is approached within one or two inches of the patient, the sensation becomes of a more tingling or burning character. Usually the American machines are sold fitted with a variety of maple sticks, some with points for a gentle convective breeze, others terminating in rounded knobs for exciting a more disruptive and stimulating discharge. These sticks are usually provided with a sliding ring for the

attachment of the grounding chain. When using electrodes of this pattern, the operator should remember to hold the stick with the ring between his hand and the patient. A head breeze is obtained by fixing at a suitable distance above the patient's head a circular metal disc, from which a number of fine metal points project, and by connecting this disc to earth through a support of suitable resistance.

The blue colour of the static breeze is due to the electrical illumination of the dust particles in the air.

Boudet, of Paris, (4) has shown that the diameter of the surface affected by the breeze is one and a half times the distance separating the point of the electrode from the surface to which it is applied.

Much confusion is liable to arise in the use of the terms positive and negative breeze. A negative breeze is administered when the patient is positively charged, for he then attracts a negative current from earth; on the other hand, if the patient is negatively charged, the breeze obtained is termed the positive breeze. The breeze in either case is conveyed by the ionization of the particles of moisture and dust in the air. If a piece of pole-testing paper (turning violet under the negative pole) be placed on the positively charged platform of the static machine, and the point of an earthed electrode be brought in contact with it for a few minutes, a pink point will develop on the paper showing the negative current; with the platform negatively charged this result will not be obtained. But on placing the paper on the ground and bringing into contact with it the point of an electrode connected with the negatively charged platform the violet colour will be obtained.

The brush discharge is conveyed by the ions in the air, the positive and negative ions travelling from earth to the patient or from the patient to earth, according to the polarity of his charge.

The point of the grounded electrode may be regarded as the small active, and the patient as the large indifferent

electrode; and as, in unipolar galvanism, we only consider the current coming from the small active electrode, and disregard the current of far lower density coming from the large indifferent electrode, so in the static breeze we need only consider the current, of opposite polarity to the charge, coming from earth to the patient through the point of the electrode, as the active current; and thus we speak of the negative breeze when the patient is positively charged, and the positive breeze when the patient has a negative charge.

### The Therapeutic Action of the Static Breeze

It is evident that the static breeze, when it is administered in its disruptive form, either from a blunt electrode, or from a pointed electrode held near the patient, thus exciting a pricking and stinging sensation, must have a considerable effect as a counter-irritant. In this way it is of some service in the treatment of the acute pain of neuritis, though the relief which it affords in such cases is only of a temporary character.

The soft convective breeze communicates to the patient the sensation of a cold draught of air blowing on the part under treatment; this breeze has been shown by French workers to have a certain cooling effect on the skin, and they state that they have found its effect persist for some time after the cessation of the treatment.

There is a considerable amount of ozone formed by the ionization of the air by the static breeze, and this may have a certain germicidal effect when the breeze is applied to wounds and ulcers, apart from its beneficial influence in stimulating an increased blood supply in these conditions.

Applied as a spinal breeze, especially in the region of the last ribs, this method is certainly of value in combination with the static charge for the treatment of neurasthenia associated with low blood pressure. In such cases the breeze should be as disruptive as can be readily tolerated by the patient; it should be applied for about

five to ten minutes; and the treatment should be concluded with a simple static charge, the patient reclining comfortably on the chair for fifteen or twenty minutes.

As a head breeze, this treatment is certainly of considerable value in sleeplessness and headaches, the result of overwork or exhaustion.

This method has been used with benefit in cases of chronic eczema and alopecia, but in such cases the ultraviolet radiation from the tungsten arc gives far better results.

Warts and similar small growths may be removed by the concentration of a static breeze of short length, but here again this treatment is far less efficient than the indirect method of diathermic coagulation.

### Sparks from the Static Machine

The so-called Static Sparks may be administered either (1) directly from the static machine with the exciting electrode connected to the negative or the positive discharging rod, usually the former, the other discharging rod being grounded; these are termed direct sparks. Or (2) the sparks may be administered with the patient on the platform, as in the static bath or breeze, and the platform connected with one of the discharging rods, usually the negative, the other discharging rod being earthed. The operator then draws off sparks from the patient by swinging, towards the part to be treated, an electrode, terminating in a metal knob connected to earth by a grounding chain, and held by an insulated handle. These are called indirect sparks. With modern machines the direct sparks are rarely used, as their effects are too severe.

### Physiological Effects of Static Sparks

Short weak sparks excite a pricking sensation, but, as the potential of the machine's output is increased, this pricking sensation gives place to one of shock.

The main effects of static sparks are two in number:

(1) local vasomotor changes; (2) the excitation of muscular and possibly also tissue or cellular contraction.

After a powerful static spark has been administered to the oedematous skin of a patient, there is at first a small circular depression, resembling a vaccination scar, much whiter than the surrounding skin; this pale anaemic area quickly gives place to a red and hyperaemic circle, which persists for some hours. If a shower of sparks is continued for some time on one spot, a blister with destruction of the superficial tissues will result.

Bordier has shown that the vasomotor effects of positive sparks are greater than those from the negative ones; he has also pointed out that, in certain conditions such as exophthalmic goitre, dermatographic lines may be drawn by a series of sparks.

The most important effects of static sparks are due to the muscular contraction they excite. Bordier has shown that direct sparks excite contractions giving myographic tracings which correspond in character with those obtained from the interrupted galvanic current, that is to say, with the negative spark a steep, sharply bent curve, with rapid rise and fall, is obtained; and with the positive spark the tracing shows a blunter, less steep curve with more gradual rise and fall. The polarity of the treatment is therefore of some importance.

When using the indirect spark, the polarity of the exciting grounded electrode is the opposite of the patient's charge, as we have seen was the case in the static breeze treatment, from which the sparking method only differs in the use of a good in the place of a bad conductor. Since in the indirect method the negative charge is usually given, the spark obtained would be a positive one.

At first sight this might appear to be the less efficient form; but it must be remembered that, whereas the direct spark would correspond to the current of make in galvanism, the indirect spark would correspond to the current of break.

Now the work already referred to of Cardot and

Laugier (5) and the experiments of Bourguignon (6) show that at the make of the current it is the negative pole which alone is active, and at the break of the current it is the positive pole only which excites contraction. We thus have an explanation why it is that with the direct spark the negative, and with the indirect spark the positive, is found to be the more effective polarity.

The degree of muscular contraction obtained from a static spark is directly proportionate to the square of the length of the spark (Bordier).

### Method of Administration of the Static Spark

It should be borne in mind that this treatment is an unpleasant one, and it should not be the method of choice if the desired result can be obtained by less painful means.

Much may be done to modify the violence of the spark. Its effect varies with the form of the exciting electrode; with a pointed electrode, a pricking or stinging sensation is experienced; with a large rounded metal knob at the end of the electrode, the sensation is more of a heavy pounding shock.

This difference is due to the larger capacity of the bigger electrode. The length, and consequently the strength, of the spark can be regulated by approximating the discharging balls of the apparatus, for the length of the patient's spark cannot exceed the distance between the discharging balls. The strength of the spark may be reduced by the operator placing a foot on the platform and so leaking away some of the current, or a chair may be placed near the platform with a similar object.

An adjustable spark gap may be placed between the exciting electrode and its attachment to earth; thus by lengthening or decreasing this gap, the strength of the patient's spark may be correspondingly increased or diminished.

The sparks should be administered by swinging the electrode towards the patient with a regular rhythm, so that he may know when to expect the shock, and care

should be taken that only one spark occurs at each swing of the electrode; the double or treble sparks which sometimes pass are far more painful than the single ones.

### The Therapeutic Effects of the Static Sparks

The vasomotor action of the static spark may be entirely neglected; if a hyperaemia of the skin is required for the treatment of an atrophic condition, such as alopecia areata, the desired effect can be far more readily and conveniently obtained by the application of ultra-violet radiation from the tungsten arc. By the excitation of muscular and tissue contraction static sparks exercise a decompressor effect on swollen and engorged tissues. By this means acutely painful conditions are often immediately relieved, especially where the pain is confined to a small area. In the treatment of tennis elbow and rider's sprain I have found static sparks of great value. Sciatica, especially when the pain is very acute, is often much relieved by this method, but I have not found it produce any lasting improvement.

### The Static Induced Current

The static induced current was introduced by Dr. W. J. Morton in 1881. It has been erroneously regarded as a form of high-frequency current, and it has been claimed that it was the first form of that current to be discovered.

In this treatment the patient is not insulated, but may be treated on any ordinary chair or couch. Two Leyden jars are connected by their inner coatings, one to each of the discharging rods. Their outer coatings are either both connected to the patient, or one to the patient and the other to earth. The jars need not be of the same size, and by varying their capacity the strength of the patient's current may be regulated. The discharging balls are placed together at the commencement of the treatment, and are then separated sufficiently to obtain the required

strength of current. Any of the forms of electrodes or pads used in galvanism or faradism may be utilized for this treatment.

As is stated above, this method is generally regarded as a form of high-frequency current, and in accordance with this view is termed by the French writers 'Franklinisation Hertzienne'. When a condenser discharges through a low resistance, the discharge is an oscillating one, but with

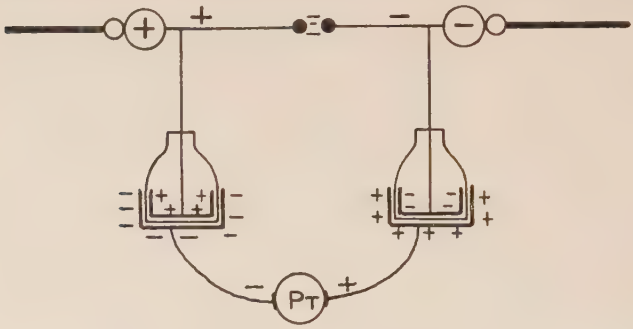


Fig. 16. The static induced current.

a high resistance the discharge is unidirectional. In fact, if R be the resistance in the circuit, L the coefficient of the self-induction, and C the capacity of the condensers, and if further

$$R^2 < \frac{4L}{C}$$, the discharge is an oscillating one.

But if

$$R^2 > \frac{4L}{C}$$, the discharge is unidirectional.

Whether a high-frequency current is developed or not in the present case would depend on the resistance in the circuit. The electrical resistance of the patient is very high; the discharge is consequently unidirectional and not an oscillating one.

The treatment is merely effected by the discharge of condensers charged at a very high voltage. Before the

spark passes across the gap a charge develops on the outer coatings of each jar; the polarity of this charge is of the opposite kind to that of the discharging rod to which the jars are attached. This charge on the outer coatings of the jars is not free to discharge through the patient until the inductive attraction of the opposite charge on the inner coatings is released by the discharge across the gap; but immediately a spark passes, then the charge on the outer coating is released and discharges through the patient. This method then amounts to a treatment by unidirectional condenser discharges, for the resistance of the body is too high to permit of any oscillations.

This view of the nature of the action of the static induced current is borne out physiologically and clinically by the definite contractions which are excited synchronously with the passage of each spark. Moreover, Bordier has pointed out that the discharges have a distinct and definite polarity, the excitations from the negative outer coatings being far more powerful than those from the positive. This definite difference in the polar action is conclusive proof that the action of the static induced current is not of a high-frequency character.

### The Method of Administration of the Static Induced Current

The patient need not be insulated; the usual rheophores, electrodes, and pads may be utilized. For the treatment of superficial areas and for the treatment of the rectum or vagina, vacuum glass electrodes, such as are used in high-frequency therapy, are very suitable. When using vacuum electrodes it should be remembered that the polarity of the current administered to the patient is the opposite of the charge on the external coating of the jar to which the electrode is attached. That is to say, that if the current conveyed to the inner coating of the jar from the discharging rod is negative, a positive charge is induced on the outer coating, and this positive charge is conveyed to the inner surface of the glass of the electrode, and induces a

negative charge on the outer surface of the glass in contact with the patient.

The strength of the current may be adjusted in two ways. (1) By increasing or decreasing the size of the jars, and thus increasing or decreasing the strength of the current. The French use a form of adjustable condenser, and these seem to possess definite advantages over the fixed sizes used in this country.

(2) The strength of the application may be adjusted by the regulation of the width of the spark gap. The wider this gap, the higher the potential at which the jars are charged, and hence the more powerful their charge.

### The Therapeutical Effects of the Static Induced Current

The therapeutic action of this current is that of a high voltage condenser discharge. The voltage of the charge can be readily raised or lowered by separating or approximating the discharging balls of the machine, and the current can be applied in the form of a surge.

It is a convenient and efficacious method for stimulation of the bladder sphincter in cases of incontinence of urine in the female. The active electrode should be connected with the jar of which the outer coating is negatively charged.

### High-Frequency Currents from the Static Machine

By connecting the outer coatings of the Leyden jars with a suitable solenoid, a circuit of low resistance and a self-inductance are obtained, resulting in a true high-frequency current. The amperage obtained in this way is very small, and the high-frequency currents so obtained cannot be compared with those yielded by the ordinary diathermy or high-frequency apparatus.

### The Nature and Therapeutic Action of the Morton Wave Current

The Morton wave current is by far the most valuable of the currents obtainable from the static machine. It was first described in a paper read by Dr. W. J. Morton,

of New York, before the American Electrotherapeutic Association, on September 23, 1900.

This current is not of the type that we usually regard as wave currents; on the contrary it is a form of treatment by sudden, and not necessarily rhythmical or regular discharges.

**Mode of Administration.** The patient is placed on the insulated platform, the negative side of the machine is

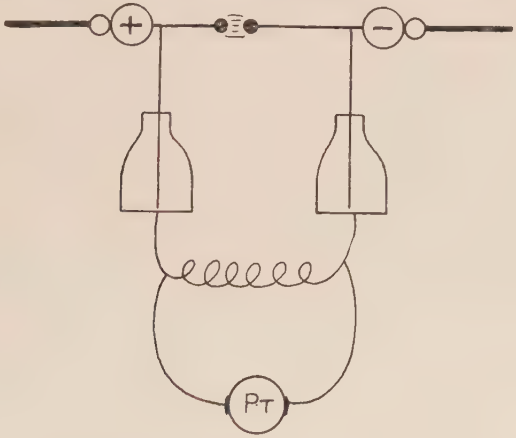


FIG. 17. Diagram showing the method of obtaining H.F. currents from the static machine.

grounded, and an electrode, connected by a wire with the positive discharging rod, is applied to the part to be treated.

The discharging balls, in apposition at the commencement of the treatment, are gradually separated to an extent proportionate to the toleration of the patient.

As the balls are separated, sparks pass between them; in the interval between the sparks, the patient is progressively charged with positive electricity, until the potential of the static charge of the patient's capacity and on the collecting combs is sufficient to overcome the resistance of the air gap. The patient's capacity then suddenly discharges with the passage of the spark across the gap, and

the muscles underlying the pad undergo a sudden and vigorous contraction, the amplitude and vigour of which is directly proportionate to the width of the spark gap and inversely proportionate to the area of the pad employed, or, in other words, is in direct proportion to the density of the discharge.

The contractions excited by the Morton wave current evidently occur at the break of the current, and this is the reason why the positive charge is more efficient in this treatment than the negative charge.

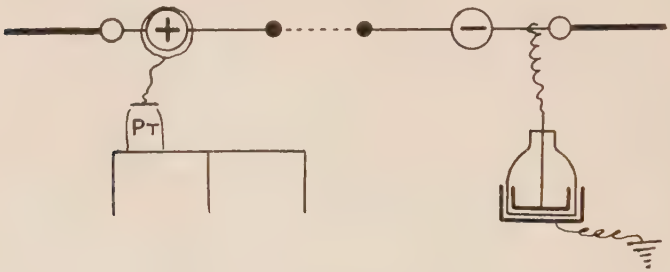


FIG. 18. Diagram of the arrangement of the static machine for the administration of the Morton wave current.

The very low milliamperage utilized to excite a contraction by the Morton wave current renders this method far less painful than treatment by the galvanic or faradic currents.

As the consequence of the minimum of pain elicited by this method, we are able to employ a voltage so high that the most vigorous contractions involving all the fibres of the muscle are elicited.

The amplitude, the frequency, and the type of contraction are under the complete control of the operator. By allowing the sparks to discharge rapidly across the spark gap, the necessary fusion of stimuli may be obtained to excite a very even tetanic contraction, and these series of stimuli may be surged gradually, either by hand or instrumentally. But the real type of the Morton wave current is the slow, steady, heavy, pounding spark eliciting

powerful isolated contractions, with a definite pause between each contraction.

The powerful and painless contractions elicited in this manner exercise on the muscles themselves and on the surrounding tissues a kind of 'muscular auto-massage', the effect of which in stimulating tissue drainage and in removing exuded lymph is incomparably greater than in the application of any form of massage applied externally to the surface of the limb.

Where adhesions exist within or in the neighbourhood of the muscles the contractions are necessarily painful at first, but gradually the toleration of a wider spark gap during the treatment indicates the removal of some of the adhesions.

The Morton wave current is extremely useful in the treatment of recent sprains and strains; the inflammatory exudate, or as John Hunter well termed it 'the coagulable lymph', is readily dispersed, and hence the pain and swelling are quickly relieved, and also the after-stiffness, due to the gluing together of the tissues by the coagulable lymph, is obviated. The efficacy of this treatment is very remarkable, the period of incapacity following a sprain being reduced from one of weeks to one of days. The massage effect of this treatment is well seen in a recent case of acute synovitis of the knee joint with effusion, the excess of fluid in the joint being frequently dispersed after twenty minutes' treatment.

By employing a suitably shaped electrode, massage of the prostate can be far more efficiently performed, and with far less discomfort, by this method than in any other way. The muscular tissue of the gland itself is thus excited to contract, and efficient drainage of the gland quickly results.

Mr. Frank Kidd (7) states: 'Massage of the prostate in obstinate cases, especially in cases with intense prostatic pain, can be most effectively carried out by using the Morton static wave applied through a rectal electrode, which produces violent but painless contractions of the muscular tissue of the prostate gland.'

Some cases of prostatic hypertrophy yield quickly to the Morton wave current with complete disappearance of the symptoms; but success in these cases naturally depends on the nature of the enlargement. Little hope of improvement can be expected from this treatment in cases of calcareous, malignant, or even fibrous enlargement. The improvement would seem to occur in lax and oedematous conditions of the gland.

One treatment by the Morton wave current often suffices to cure a case of recent lumbago. Supposing this condition to be due to hypertonus of the muscles on the affected side, it would be difficult to conceive a more certain way of overcoming this hypertonus than by the powerful muscular contractions excited by the Morton wave current.

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# PART III

# THE THERAPEUTIC ACTION OF RADIANT ENERGY

## CHAPTER I

## THE THERAPEUTIC ACTION OF RADIANT HEAT AND LIGHT

RADIATION, or Radiant Energy, is the force transmitted by the ether in the form of waves resulting from the periodic vibration or rotation of electrons.

The Hertzian waves, such as those used in wireless telegraphy, have the longest wave length and the lowest frequency; they are set in motion by spark discharges from condensers. The next in order of decreasing wave length and increasing frequency are the heat waves. These are set up by the electronic discharges which are excited by the radiation from heated substances. As the waves further decrease in the length, and increase in the frequency of their vibrations, light waves are produced. Light waves extend down through the visible spectrum from the red, orange, yellow, green, blue, indigo, to the violet: beyond which the vibrations become too rapid to stimulate the human retina, and we enter the ultra-violet region of actinic or chemically active rays. Beyond this is a region, in which the vibrations are too rapid to affect photographic plates or otherwise to reveal their nature and properties by means of any method formerly at our disposal; but by the adoption of new methods of investigation, physicists are step by step filling in the gap between the U.V.R. and X-rays and the gamma rays of radium. Following the gamma rays come the Cosmic rays and the other forms of radiation, if any, yet to be discovered.

The study of radiant energy is one of the most complex

# TABLE OF WAVE LENGTHS

(From *Principles of X-ray and Radium Dosage*, Albert Bachem, Chicago, 1923.)

| Radiation | Wave Length | |
|---|---|---|
| Electric waves | 10 kilometers to 1 millimeter | Wireless telegraphy, diathermy |
| Infra-red or heat waves | 0·3 millimeters to 0·00077 millimeters–7700 AU | Longest mercury vapor radiation |
| Visible light | 7700 AU to 400 AU | Red, violet |
| Ultra-violet rays | 4000 AU | Near ultra-violet limit of sun's spectrum |
| | 3000 AU | |
| | 1800 AU | Far ultra-violet, bactericidal |
| | 200 AU | Shortest observed ultra-violet radiation (Millikan) |
| X-rays | 725 AU | Longest known Roengten radiation (December, 1923) |
| | about 5 AU | Radiation used for diagnostic purposes |
| | about 0·3 AU | |
| | about 0·3 AU | Radiation used in deep therapy |
| | about 0·06 AU | |
| | 0·058 AU | Hardest X-rays, Dessauer and Back (1919) |
| Radium rays | 0·1 AU | Soft $\gamma$-rays |
| | | Hard $\gamma$-rays |
| | about 0·025 AU | Estimated from observations by Rutherford, Andrade, Compton |
| | 0·01 AU | Limit not definitely known |

and difficult in the whole range of physical science. So far as therapeutics is concerned, the action of radiant energy may be divided into the action of radiant heat obtained by artificial means; heliotherapy, or the action of heat and light radiation obtained from the sun's rays; the action of ultra-violet radiation; and the action of the radiation from radium and the Röntgen rays.

### The Therapeutic Action of Radiant Heat and Light

To a certain limited extent the effects of radiant heat and light vary in accordance with the method adopted for their administration; for, even in the most elementary method, namely, that of heliotherapy, in which the radiant heat and light energy are obtained from the sun's rays, free from the interposition of any filter or absorbing medium other than that of the atmosphere, the effects vary as the treatment is administered at the sea-level or at the high altitude of the Alps.

In the cold sun bath, as administered in the Alps, the snow absorbs some of the heat rays and reflects the light rays; the rarefied atmosphere also filters off less of the ultra-violet rays than the denser atmosphere at lower altitudes.

In the sun bath administered at high altitudes there is thus a maximum of light rays, an increased ultra-violet radiation, and a diminution of the heat rays.

In the warm air of the sun bath of the Mediterranean, though more of the ultra-violet radiation is filtered off, and though there is no snow to reflect the light rays, there is in the hot air little loss of the heat rays from radiation; this, then, is the true sun heat bath, 'loved by swans and lizards, and as a general rule by all living beings' (Laroquette (1)).

In treatment by means of incandescent lamp baths, by far the most powerful action is that of the heat or infra-red region. Laroquette (2) states that in the solar spectrum there are about six octaves of infra-red rays, about one octave of luminous rays, and nearly half an octave of ultra-violet rays of from 0·4 to 0·3.

The percentage in the spectrum of the incandescent lamps he gives as follows:

| | *Infra-red Rays.* | *Luminous.* | *Ultra-violet.* |
|---|---|---|---|
| Incandescent carbon lamp | 93% | 6% | 1% |

The very small amount of ultra-violet rays shows what a very small part this form of radiation plays in the therapy of the light bath.

The very large proportion of heat or infra-red rays in the above table explains why in ordinary clinical practice we detect little or no difference between the effects of radiant heat administered by light baths and the convective heat of hot air baths, or the conductive heat of electrically heated wire resistances, such as the Grevillite appliances, or by the use of hot sand, &c. The greatest advantage of the incandescent light bath consists in the safety, the convenience, and the ease of its administration. In such cases, from whatever source the heat is derived, it is absorbed as heat and its energy is converted in the tissues into some form of increased cellular activity.

There is no basis for the belief that the colour of the incandescent lamps in any way affects the efficiency of the treatment.

Apart from any specific action which may be attached to the sun's rays, we must recollect that heliotherapy is administered under the best conditions in the open air, usually at sanatoria, where the patient is at complete rest, free from all the cares and worries of business or household duties, where the diet is carefully prepared and regulated to suit the patient's complaint and condition, and where regulations are enforced in respect to early retirement to bed. The treatment is applied gradually, with a low and easily tolerated intensity, for several hours at a time, thus realizing that very important, though much overlooked, rule of physical therapeutics, that it is far better to apply the treatment at low intensities extended over long periods than to apply it intensively for a short time.

Moreover, in heliotherapy there is the invigorating, but

unexplained, physical and moral effect, which is excited by bright sunlight, which so cheers and encourages the patient. Unfortunately these superior concomitant effects of the sun bath are but rarely obtainable in this country, and we have to make the best use we can of artificial light and heat baths.

The shorter rays and the higher frequencies of ultra-violet radiation play a very small part in the treatment by incandescent light baths. The fact that pigmentation follows prolonged exposure to the incandescent lamps, whether of the smaller or the larger type, is not attributable to the action of ultra-violet radiation: in such cases the pigmentation is due to the prolonged but weaker pigmenting action of the blue and violet rays.

The infra-red and the red rays have no pigmenting effect, but they have a more penetrating action, reaching the subcutaneous regions, and dilating the capillaries in those parts. By their prolonged action deeper effects are consequently obtained, and these are shown by the deeper oedema of the tissues which results from their intensive application.

The effect of the incandescent light baths is to increase the temperature of the skin and subcutaneous tissues and so to increase the cellular activity of these regions: this is shown by the increased sweating which follows their application.

In fact, the sweating which follows the application of the enclosed light baths is apparently far greater than that which follows the treatment by the sun bath, where the part under treatment or the whole body is exposed to the free circulation of the air, and consequently the moisture of the skin rapidly evaporates.

The bactericidal action of these baths may be disregarded; only the least resisting of bacteria are destroyed even by sunlight, and their destruction is perhaps due more to desiccation than to any direct action of the radiation.

There is one very interesting point which has been raised abroad, and also in those sanatoria in this country where

the sun bath has been employed for the treatment of tuberculous glands, bones, or joints.

It has almost invariably been noticed that no improvement has resulted from the sun bath unless pigmentation has occurred. And this has been found to be so universally the case that the relationship has been regarded as one of cause and effect. Laroquette (3) points out that this inference is an incorrect one, and that the relationship is explained by the fact that only those cases are capable of improvement whose cells have sufficient vitality to respond to the stimulus of the radiation. The correlation is not therefore one of cause and effect; but merely shows that the radiation affords a valuable method of prognosis, by differentiating, by means of the occurrence or absence of pigmentation, between those cells which have sufficient vitality to respond to the radiation and consequently possess the power of recovery, and those cells whose vitality is too far lowered to admit of any response to the radiation and which consequently have not the power of recovery or improvement. This point has further some practical importance, for it has been wrongly urged, by those who maintain a cause and effect relationship, that no form of treatment, such as ultra-violet radiation, should be adopted which would tend to prevent subsequent pigmentation on exposure to sunlight.

To sum up the effects of heat and light radiation, we find that these forms of radiant energy are conveyed to, and are transformed into, heat in the skin and subcutaneous tissues. And we find that, clinically, little, if any, difference occurs in the therapeutic action, whether this heat is conveyed to the tissues by the conductive heat of paraffin wax baths, hot sand, or the electrically heated wire resistances of the Grevillite apparatus, or whether it is conveyed by convective heat as by hot air, or applied as radiant heat by means of incandescent lamps. The choice of method should be decided upon grounds of convenience, safety, and efficiency. Acting on this principle, the incandescent lamps, either in the form of a

battery of 16 c.p. or 32 c.p. carbon lamps, or one large 500 c.p. carbon filament leucodescent lamp, or the heliodescent lamp of 2,000 c.p. with metal filament, will be selected. The enclosed battery of small lamps should be selected where it is desired to excite profuse perspiration, and either the leucodescent or the heliodescent lamp will be found useful where it is desired to observe the degree of heating during the treatment, or to treat certain irregular surfaces to which the collection of smaller lamps cannot conveniently be applied. Nephritis may be treated, with a view to promoting profuse perspiration and consequent relief of the kidneys, by a trunk bath containing about sixteen incandescent lamps of 16 or 32 c.p.

Light baths surrounding the whole body, with the exception of the head and face, may be utilized; and to some of the baths three arc lamps are added, but the benefits derived from their use do not compensate for the additional expense and complication that they entail. The trunk bath, or two trunk baths, the one covering the trunk and the other the legs of the patient, are equally efficient as the full body bath, and are far less expensive and cumbersome. Such a combination of baths is useful for the treatment of neuritis or rheumatism, when it is distributed over the whole or greater part of the body. The smaller baths are usually employed for the treatment of rheumatism or neuritis of the joints or limbs, or as a preliminary to massage.

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## CHAPTER II

## ULTRA-VIOLET RADIATION

THE wave length (symbolized by the Greek letter lambda, $\lambda$) of light is usually stated in Ångström Units. An Ångström unit is the wave length of soft X-rays, i. e. $1/10^{-10}$ (1/10,000,000,000) of a metre.

The wave length of the visible spectrum commences at the beginning of the red end of the spectrum, $\lambda$ 7,500 A.U., and extends to $\lambda$ 3,900 A.U. at the end of the violet. At this wave length the ultra-violet spectrum commences and extends for therapeutic purposes to $\lambda$ 1,850, where the atmosphere absorbs all the shorter radiations, and they consequently cannot be utilized for treatment purposes. Schumann and Lyman have extended the ultra-violet spectrum, by the use of special methods, up to $\lambda$ 600, and more recently Millikan has added a further extension to $\lambda$ 360. The unexplored portion of the spectrum, which until recently existed between this wave length and that of soft X-rays is rapidly yielding its secrets to modern physical investigation, but so far no radiation of therapeutical application has been revealed. The value of the soft X-rays, as previously stated, is that of one Ångström unit. Hard X-rays from a gas tube are equal to about 0·25 A.U. The hardest X-rays obtainable from a Coolidge tube are about 0·14 A.U., and the very penetrating gamma rays from radium have a wave length of about 0·07 A.U.

The earliest paper to allude to the lethal action of the actinic or chemical rays (i. e. the ultra-violet rays) on bacteria with which I am acquainted, appeared in the *Proceedings of the Royal Society* of December 26, 1877. (1) This was a paper entitled 'Remarks on the Effect of Light on Bacteria and other Organisms', by A. Downes and T. P. Blunt. The experiments therein described were performed chiefly to show the retarding effect of sunlight on the development of hay bacilli placed in thin glass test-

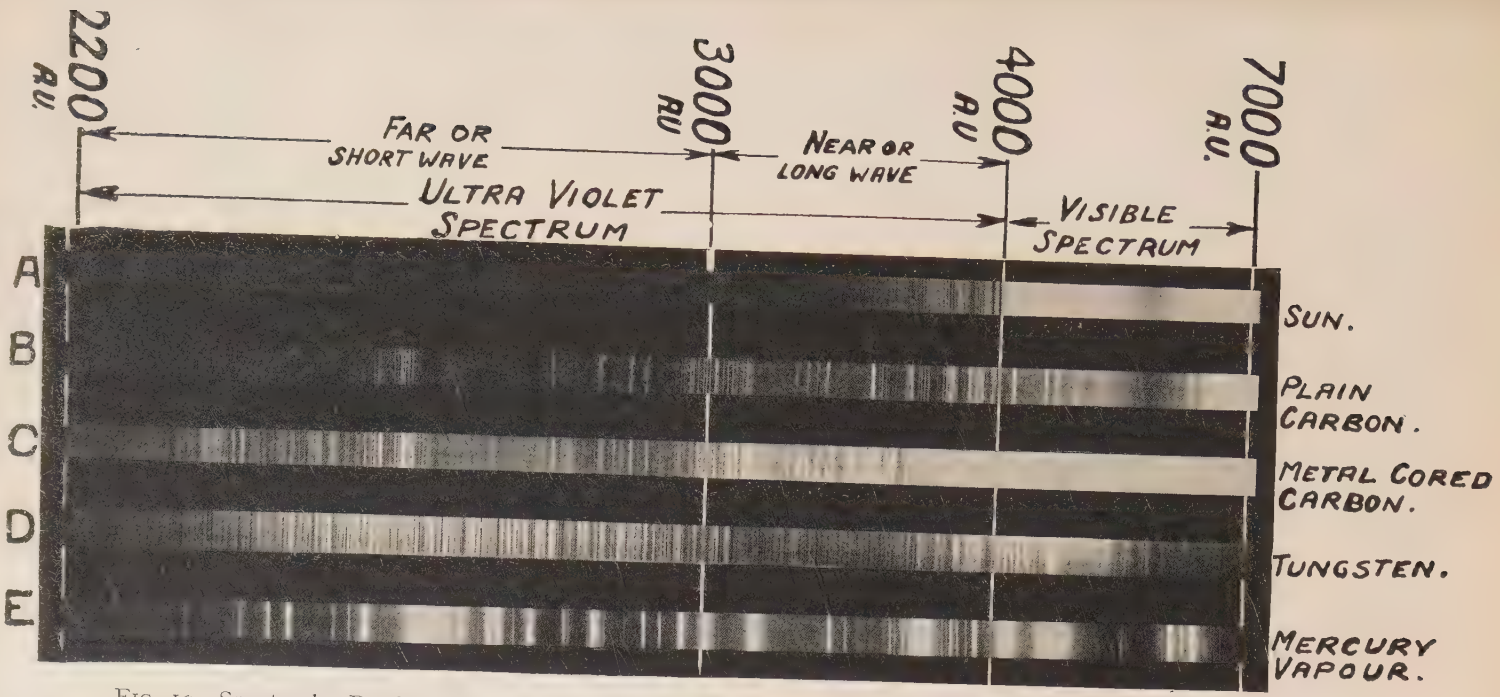



FIG. 19. Spectra by Dr. Judd Lewis. Reproduced by permission from *Ultra-Violet Therapy*, W. E. Schall, B.Sc.

tubes. The authors made the significant observation: 'We have invariably found it a difficult matter to sterilize an ordinary cultivation liquid, when a second screen of glass was placed between it and the light.'

This passage clearly shows that the retarding effect on putrefaction was due to the higher frequencies of the radiation, which were cut off by the interposition of the glass screen, and the authors concluded, as the result of their experiments, that 'the preservative quality of light would appear to be chiefly, but perhaps not entirely, associated with the actinic rays of the spectrum'.

In 1887 Hertz pointed out that the discharge across a spark gap took place more readily when ultra-violet light fell upon it. Ebert then showed that this action occurred at the negative pole, and it was subsequently shown to be due to the fact that a negatively charged body readily loses its electrical charge when ultra-violet light falls upon it. Thus it was established that the photo-electric action of ultra-violet light consists in the discharge of electrons from a negatively charged body 'or the acquisition of a positive charge under the action of light. This is traced to the emission of electrons from the illuminated surface' (Allen).

Hertel, as the result of his investigation into the lethal action of ultra-violet radiation on bacteria, concluded that the action was due to reduction, because he found that, probably owing to the protection obtained from the oxygen supplied by the chlorophyll, green hydrae were less affected by ultra-violet light than the colourless ones. He also found that oxyhaemoglobin was reduced, and that, when the brain of a rabbit, coloured blue by the action of alizarin blue injected into the veins of the animal, was acted upon by ultra-violet light, the blue colour disappeared as the result of the action of the light.

It was found during the war that the cotton wings of the aeroplanes quickly perished under exposure to sunlight at the higher altitudes, and 'dope' was consequently applied to protect them from the shorter wave lengths of

the ultra-violet region. Some interesting experiments were performed in the investigation of the cause of this deterioration. Strands of cotton were exposed to different parts of the spectrum, and by delicate apparatus their breaking strain was subsequently tested. The tabulated breaking strains thus recorded gave a numerical representation of the spectrum, the least breaking strain being recorded for those strands which had been exposed to the shorter rays of the ultra-violet region.

There appears, then, to exist an accumulation of evidence, derived from different sources and from various observers, that the action of U.V.R. on the tissues is one of oxidation or reduction. But in what way is this action produced? By what means does it exercise its therapeutic effect on the tissues?

It is impossible to appreciate an answer to the first question unless we possess some conception of the structure of the atom.

Until the discovery of X-rays by Röntgen, the atomic theory, foreshadowed by the Greek philosophers, formed the fundamental basis upon which the science of chemistry was erected. Among the many wide-reaching results that have followed Röntgen's discovery, none has had a more important or revolutionary effect than the knowledge which has been obtained by its means of the structure of the atom.

It is now held that the atom is made up of a number of electrons (particles of negative electricity) held together by the electrostatic attraction of a central complex nucleus with an aggregate positive charge equal to the number of outside electrons. The aggregate positive charge is made up of a number of protons which are numerically equal to the atomic electrons. The electron is the unit of negative electricity, and the proton has a charge of positive electricity equal to the negative charge on the electron. The chemical properties and the characteristics of the different atoms depend upon the number and grouping of these electrons. The simplest form of atom is that of hydrogen, which has only one electron and one proton; the next in

order of simplicity of structure is the helium atom, with two electrons and two protons. The atoms of the various elements possess an increasing number of electrons, until we arrive at lead with 82 electrons and protons and radium with 84 electrons and protons. The arrangement of the electron in relation to the central nucleus is of importance from the point of view of atomic and molecular stability. Langmuir suggests that the electrons are arranged concentrically round the central nucleus of positive electricity; if there are not more than two electrons, they are arranged in one concentric ring; if more than two electrons, the next eight are arranged in a second concentric ring, further removed from the electrostatic attraction of the central nucleus of positive charge. As the number of electrons comprising the atom increases in number, there is another layer of eight; then one or two layers of eighteen, and if there are still more electrons, there may be an outer layer of thirty-two electrons. The arrangement of the electrons in the second and third layers is a symmetrical one, the electrons taking up a position as at the eight corners of a cube (Langmuir)—an arrangement termed octets, presumably due to the mutual repulsion of the electrons bearing a similar charge. The chemical activity of the atoms depends on the readiness with which they take up or part with electrons. These electrons are grouped in this form in a very open network. Langmuir has given an ingenious simile which enables us to visualize the relative minuteness of the particles which we are considering. He states that if a lump of matter the size of a base-ball were magnified to the size of the earth, the atoms of which the lump of matter was composed would then have become the size of the base-ball. Or, in other words, the relative size of the atom to the base-ball is that of the base-ball to the earth. He further illustrates the open network in which the electrons are arranged, by supposing that if the diameter of the atom is one mile, the nucleus would then be the size of a walnut, and the electrons would be about 5 feet in diameter. This method of realizing the minuteness

of the particles may be completed by recalling the simile of another writer, that if we imagine an ordinary buck shot covered with electrons, then increase the size of the electrons until they are of the size of the buck shot, and next increase the size of the buck shot in a similar ratio, the buck shot will become 48,000 times the size of the earth.

The electrons within this loose network of the atom rotate in an electrical field exercised by the positive charge of the central nucleus. The stronger the electrical field the firmer is the combination of the molecules composed of these atoms, and to a corresponding extent the chemical activity of these molecules is reduced. Now light, in accordance with the Law of Grotthuss, is only active when it is absorbed, and is only absorbed when its wave length is in resonance with, that is to say, when its vibrations correspond with, those of the atoms upon which it falls. It consequently follows that the molecules composed of the atoms with higher natural frequencies will be acted on by the shorter wave lengths of the ultra-violet end of the spectrum; these are generally more stable and less chemically active than those molecules whose vibrations correspond with the longer wave lengths of the red end of the spectrum. The effect of this absorption of waves of similar length is an activation of the absorbing molecules acted upon, usually resulting in oxidation or reduction.

We thus conclude that the effect of U.V.R. is to produce an oxidation or a reduction of those molecules whose vibrations have the same frequency as the radiation which falls upon it; and that this oxidation or reduction is the result of the resonant agitation excited in the atoms.

This resonant agitation in the atoms is excited in the following manner. The activation or electronic disturbance in an atom occurs when the wave length of the radiation is in resonance with the atomic electrons. The shorter wave length of X-rays is more in resonance with the atomic electrons in close proximity to the nucleus, whilst U.V.R. is more in resonance with the marginal electrons. The chemical changes and resulting chemical effects are greater

when the electronic disturbance takes place near the nucleus than when it occurs in the marginal orbits. It is probably on account of this that X-rays produce a more profound action on the atom than U.V.R.

When the radiation is in resonance with an atomic electron it may either cause that electron to move from one concentric ring of the orbit to another, or it may cause it to shoot out into space. In this movement from one concentric ring to another, or from the atomic orbit into space, these electrons radiate a wave length that is characteristic of their type of atom.

An atom becomes unstable after its activation has resulted in the movement of an electron either from one ring to another or out into space; and, when it is in this condition, is said to be 'photo-electric'. This photo-electric state is due to the tendency that exists for another electron to fall back into the ring or space formerly occupied by the displaced electron. In this replacement, the electron, which is falling back, sets up a secondary radiation of a longer wave length than the activating radiation. 'In some forms of matter the return of the energized electron to the normal, accompanied by the emission of radiation, occurs at once and we call the phenomenon, when we see it, "fluorescence". In others the return may be delayed for minutes and even hours and we are then dealing with "phosphorescence".'* (Schall (2).)

After the application of ultra-violet radiation a latent period of about five or six hours, varying with the wave length and intensity of the radiation, elapses before the characteristic erythema appears. During this latent period nothing is noticed, and it is, indeed, comparable, except for its much shorter duration, with the latent period following a full skin dose of X-rays. Any satisfactory explanation of the therapeutic action of U.V.R. should explain this latent period.

* The author expresses his indebtedness to the very lucid exposition of the physical action of U.V.R. contained in Bulletin 1008, December 1927, by W. E. Schall, B.Sc.

It has been suggested that the oxidizing action of the U.V.R. may result in the production of ozone within the tissues, and that the erythema is the result of the irritation caused by that product. The erythema from such a cause would probably be more immediate and less lasting in its action.

The erythema caused by U.V.R. is very slow in its disappearance and may persist for a week or more; its disappearance is not in the form of a uniformly gradual retrogression, but it is subject to three periods of exacerbation and decline, each of the exacerbations being relatively less than its predecessor.

The U.V.R. erythema appears to be due to the formation, during the latent period, of some irritant product formed by the breaking down of protein molecules.

A protein has been defined as 'a long and complicated chain of amino acids' (Halliburton). When such a chain of amino acids is broken up, a number of most complex organic acids are formed. Among these products one of the most important appears to be the amine 'histamine' which is derived from histidine. An exceedingly small amount of this product is capable of producing shock, so powerful is its action in reducing capillary tone and dilating the capillaries. A further consideration of such chemical problems as these is beyond the sphere of the electrotherapist: he should, however, be aware of the existence of such biochemical products, and be ready to recognize the profound effects that may follow their liberation from the cells.

It would appear from the work of Köhler that the nuclear chromatin in the cells primarily absorbs the U.V.R.; and, consequently, we may infer that it is primarily from the nuclear protein that the irritative chemical derivatives are formed.

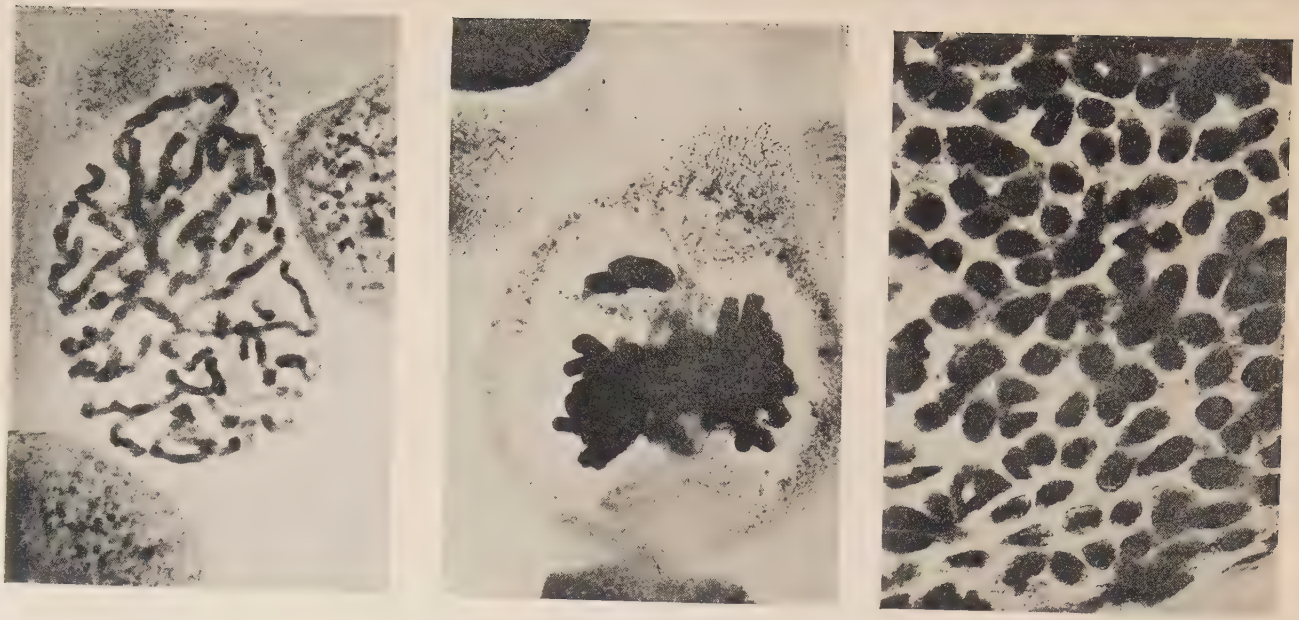
Köhler's (3) experiments were not conducted with any reference to the biological action of U.V.R.; he merely utilized U.V.R. of $\lambda$ 2,800 to obtain micro-photographs, without resorting to staining, of the nuclear chromatin.

His efforts were entirely successful, and he obtained photographs of the cells in the gill plate of a salamander larva, and in the sternal cartilage of the newt, in which the chromatin came out as opaque as if it had actually been stained. He thus incidentally demonstrated that the chromatin is the first part of the cells to absorb the U.V.R., and is, consequently, the first part to be activated by the radiation.

It would appear that the main effects of U.V.R. are not due directly to their primary action: but to the effects of some products, the exact nature of which we must leave to the biochemists, that are formed during the latent period primarily by the radiation splitting up the nuclear chromatin, and, possibly, also, by its action on other parts of the cells. We would further conclude that, owing to the action of such products, a local hyperaemia ensues; and, also, that a reflex stimulation takes place consequent upon the excitation of the afferent nerve endings by the irritant products, and that this reflex stimulation may have effects of a most complex and wide-reaching character.

It has been suggested by several workers that certain wave lengths may have a specific action on certain cells and under certain conditions. The action of U.V.R. on strands of cotton (quoted above) uniformly and evenly decreases in its effects as its wave length increases, and exhibits no such selective action. It cannot, in the present state of our knowledge, be definitely concluded from this that no variation, of the kind suggested, occurs in living tissues; but no such specific action has been shown to occur, and clinical experience is in favour of the effects being in an inverse ratio to the wave length. This conclusion is also in accordance with the physical action of U.V.R., for, as has already been pointed out, the shorter the wave length the greater is the depth in the atomic orbit at which its energy will be absorbed; and the greater the depth of its absorption the greater will be the effects produced.

From a series of experiments conducted on human skin



A B C

Fig. 20. A and B. Photographs by means of U.V.R. of (Lanlode) 2,800 A.U. of the unstained dividing nuclei in the gill plate of a salamander larva, showing the complete absorption of the U.V.R. by the chromatic substance.

C. The edge of the sternal cartilage of a living newt photographed in a similar manner, showing how completely the nuclei have absorbed the radiation.

From A. Köhler, 'Mikrophotographische Untersuchungen mit ultraviolettem Licht', *Zs. wiss. Mikros.*, xxi, 273–304.

obtained fresh from the operating theatre, Nogier found that the skin, after it had been freed from blood and fat, absorbed U.V.R. to the following extent: Skin 6/10 mm. thick transmitted the visible spectrum, but cut off all the short wave radiation, only transmitting such U.V.R. as would pass through ordinary glass. Skin 4 mm. thick transmitted the red, green, and blue radiation, but totally absorbed the U.V.R. 40 mm. of skin totally absorbed the luminous radiation. (Nogier, *Revue d'Actinologie*, October 1926.)

The erythema excited by U.V.R. has been classified into four degrees or stages.

First degree. The erythema exhibits a faint pinkness of the skin; no abnormal sensation is excited beyond a slight tenderness when the patient enters a hot bath. A slight powdery condition of the skin may ensue.

Second degree. Faint redness of the skin followed by a branny desquamation. Slight soreness of the skin is appreciated.

Third degree. A distinct red reaction of the skin accompanied by some irritation. Epidermis peels off in flakes.

Fourth degree. Deep red colour of the skin, blisters are formed, and the skin is very sore.

In constitutional treatment we aim at not exceeding the second degree. In local treatments the third or fourth degrees may be needed according to the depth and nature of the lesion.

There is a very wide range of susceptibility to U.V.R. in different patients: in extreme cases it may vary as 6 to 1. It is evident, therefore, that the appreciation of the patient's susceptibility is of more importance than the measurement of the radiation. This varying idiosyncrasy can be best allowed for by administering a minimum dose at the first application, noting its effect and adjusting the subsequent dosage accordingly. It may be laid down as a general rule that blondes are more susceptible than brunettes, and young children and the aged react more violently than the middle-aged. The patient at the first

visit should be asked if he sun-burns readily, as the answer to this question often affords a useful guide to the dosage required.

Parts of the body habitually covered by the clothes are specially sensitive. It requires a large dose to produce a reaction on the hands or on the soles of the feet.

The operator should test the power of a new lamp by a series of graduated exposures on the flexor surface of his forearm through a small circular opening in a protective covering of paper or other material.

It is clear that we must distinguish between the local and the general or constitutional administration of U.V.R. In local treatments a strong reaction is usually required. A third degree erythema may be sufficient for the treatment of a case of acne where the comedones are small and superficial: but a fourth degree erythema will be required where they are large and indurated. The success of the treatment of many lesions depends entirely on the administration of the correct dose, and failure frequently ensues from an insufficient dose having been administered. It is the violent reaction and the tension induced in the affected part that often brings about the cure.

I have seen a very severe case of calf ring-worm of the face with three seats of infection, one on each side of the face and one on the chin, cured completely by fourteen applications of U.V.R. pushed to the fourth degree: and I have also seen a case of severe brachial neuritis in an old man completely cured by one fourth degree U.V.R. erythema after several applications of diathermy and galvanism had failed to give any relief.

I am convinced that in both these cases a mild dose of U.V.R. would have produced little or no result. Both lupus vulgaris and lupus erythematosus require fourth degree erythemata to produce satisfactory results.

Among the local conditions suitable for treatment by U.V.R. the following may be mentioned: alopecia areata, tinea cruris, impetigo, chronic eczema, acne, acne rosacea, herpes, paronychia.

U.V.R. to the first or second degree of erythema is most valuable as a preparation for skin grafting (see Fig. 21). I first tried this procedure during the war with very satisfactory results, and I have since employed it for preparing extensive burns for grafting. Cases, in which every graft has failed to grow without previous radiation, have been subsequently grafted with complete success after a preliminary radiation.

It is not difficult to visualize the manner in which the curative action of U.V.R. on local lesions is brought about; and the results of this treatment, when administered with sufficient intensity, leave no doubt of its efficacy. With general or constitutional treatment both the explanation of its mode of action and the demonstration of the resulting benefits are naturally more difficult. For, in place of the immediate benefits which are actually seen to occur after one or two local treatments, when dealing with constitutional disease we have to be content with such vague and indefinite phrases as 'an improvement in the general health', 'the production of a sense of well-being'.

A widely held theory lays it down that the curative effects of U.V.R. in rickets are due to the formation of vitamin D from the ergosterol contained in the cells of the skin.

It was at first thought that the vitamin D was obtained from cholesterol, and as it needed thirty days' exposure to the July sun to produce it from this substance, it was difficult to understand how ten minutes' exposure to a mercury vapour lamp could produce it in effective quantity in an irradiated patient. It has since been found, however, that pure cholesterol does not yield vitamin D on irradiation, and that the cholesterol originally experimented with contained some ergosterol as an impurity. The maximum antirachitic properties are now obtained from ergosterol in thirty minutes, or even less exposure to a mercury vapour lamp at 20 c.m. distance; so that there is nothing improbable in the theory that vitamin D is formed in the cells of the skin during ten or twenty minutes of an ordinary clinical application of U.V.R.

Shipley has shown that animals exposed to a short wave radiation, the most effective being $\lambda$ 2,100, were able to compensate for a faulty calcium phosphorus ratio. He

FIG. 21. Case of G.S.W. of shoulder. A sloughing and septic wound. Treated, 1916, by U.V.R. from the tungsten arc. The wound rapidly cleaned under the radiation, and twelve days after the patient's admission to the hospital the wound was skin grafted by the tinsel method. All the grafts were successful. The photograph was taken twelve days after the skin grafting.

found that irradiation produced the same effects as the administration of cod liver oil. Eckstein, on the other hand, found that rats, fed on vitamin-free diet, died sooner when exposed to U.V.R. than other rats to whom no radiation had been administered.

It has been found that when rats are fed on a food, such as milk, lard, or liver, which has been exposed to U.V.R., growth and bone calcification are promoted to the same extent as when the rats are directly exposed to U.V.R. It has consequently been suggested that the food of rachitic children should be irradiated with a view to the formation of this anti-rachitic substance (vitamin D). Professor Drummond has, however, shown that milk irradiated in this manner becomes unpalatable, has a tallowy smell, and undergoes other changes that lower its nutritional value. (4) With so many anti-rachitic food substances available the process of irradiation of the food may be dismissed as unnecessary or even harmful.

Kugelman and MacQuarrie state that 'The experimental data further show that the oxydized substances curative of rickets when exposed to U.V.R. liberate oxygen. Therefore the photo-chemical reaction appears to be reversible and may be expressed by the equation:

Oxygen + Ricket-curing substances = Oxy-substances + U.V.R.' (5)

The vitamin D formed by the action of U.V.R. on the ergosterol contained in the cells of the skin is supposed to enter the circulation through the lymphatics and, in some way not at present explained, aid the absorption of phosphorus and calcium from the bowel: it is also suggested that it may in some unknown manner 'act on the physiological or chemical activities of the osteoblasts'. There are still many links missing in the chain of evidence relating to the anti-rachitic action of the vitamin D obtained as the result of radiation.

A suitable vitamin D diet can be so easily obtained that, provided the action of U.V.R. depended solely on its production of this anti-rachitic substance, there would be no justification for adopting the relatively elaborate and expensive technique that its employment necessitates. The therapeutic effects of constitutional U.V.R. are not, however, entirely or even mainly due to the production of vitamin D. Such a supposition in no way explains the

erythema, and it is to the consecutive effects of this erythema and to the stimulation of the afferent nerve endings in the skin which causes it that we must look for a more adequate explanation of the curative action of U.V.R. whether applied as a local or as a general treatment.

In chapter I of Part II in dealing with the general principles of electrotherapy we found that an improvement in the general health similar to that obtained from U.V.R., resulted from very divergent methods of physical treatment. And we further found that there was one factor alone, the stimulation of the afferent nerves of the skin, that was common to all the methods. Hence we concluded that the constitutional benefits obtained from such entirely different methods as general galvanism, spray douches, static charge and breeze, exposure of the naked body to the cold air, &c., were mainly due to the reflex stimulation of the organs and ductless glands of the body through the medium of the afferent nerves. Since Nature does not operate in watertight compartments, it is by taking a wide view rather than by restricting our observations to an isolated example of her methods that we are more likely to penetrate her secrets.

The theory of reflex stimulation not only affords an explanation of the action of U.V.R., but also provides us with an indication of the class of case for which it should be employed, and further gives a clue to the most suitable method for a particular class of case.

One of the chief claims that can be put forward for the selection of U.V.R. is the long duration of the effect that follows its application. In most of the methods quoted above the stimulation only exists during the actual administration of the treatment: but in the case of U.V.R. a stimulation, as shown by the erythema, persists for a week or ten days, and during this period rises and falls with decreasing intensity at three distinct intervals.

Many observers have noted that debilitated children have derived more benefit from the exposure of their naked bodies for several hours a day to the cold air than from a

few minutes' daily exposure to U.V.R. And it is quite to be expected that the stimulation of the cold air, suitably tempered to the shorn lamb, would raise the basal metabolism of the child more than exposure to U.V.R. In ordinary life we know from our own experience how our appetite is increased and a sense of well-being created by a walk on a windy moor or by a thrash to windward in a sailing boat. U.V.R. is no substitute for such open-air exercise, and there appears to be a danger in this mechanical age that we may become accustomed to taking our exercise in motor cars and to substituting U.V.R. for the stimulus of the open air.

It does not, however, fall to the lot of everyone to be able to utilize such ideal methods of recuperation as are afforded by Winter Sports and other outdoor recreations, and it is only the very young to whom the unrestricted exposure of the naked body is permissible: there is consequently a large field of usefulness for constitutional treatment by U.V.R.

It is especially useful to those recovering from bronchitis, pneumonia, or any other exhausting disease. The results obtained from the administration of U.V.R. in cases of tubercular glands in the neck leave no doubt of its therapeutic value.

In order to obtain an opinion of the value of U.V.R. in the treatment of debilitated children, independent of that held in the light department, a mercury vapour lamp was installed in one of the two children's wards of the Radcliffe Infirmary, Oxford: and, after a short course of instruction in its use, the administration of the treatment and the selection of the cases were left in the hands of the Sister of the ward. There was no question in regard to the good results obtained, and only a very brief interval elapsed before a similar lamp had to be provided for the other ward. Judging from the results obtained, an U.V.R. lamp is indispensable for a completely equipped children's ward, the administration of the treatment in the ward having so many advantages over its application in a light department.

Ultra-violet radiation may be generated either by a spark or by the arc discharge; but as the spark discharge does not yield a sufficient volume of radiation for therapeutic purposes, the latter method is the one usually chosen. When a substance is heated to incandescence, as in the case of the filaments of incandescent lamps, a continuous spectrum is obtained common to all metals in a state of incandescence, and the composition of the filament in no way affects the character of the radiation. The spectrum of incandescence stops abruptly at about $\lambda$ 3,700 A.U., and is consequently of no practical value for ultra-violet treatment. When metal rods or mercury are employed as electrodes in the electric arc, they become heated to volatilization, and yield a type of spectrum that is specific to the metal employed.

The carbon arc, the mercury vapour arc, the iron arc and spark, the Simpson (wolfram) arc, and the tungsten arc are the sources most commonly employed for therapeutic purposes. The carbon arc has the distinction of having been the one selected by Finsen, who did the pioneer work on this subject, and whose investigations have been of the greatest value. The carbon arc is not, however, a rich one in the shorter wave lengths of the ultra-violet region, and the Finsen lamp necessitates an exposure of about seventy minutes, a current consumption of about 80 amperes; and an area of only about an inch in diameter is treated at a single treatment. The iron arc is very rich in ultra-violet radiation, containing some very intense lines, which extend to wave length 2,250, but its spectrum is not so continuous as that of the tungsten arc.

The mercury vapour lamp does not yield by any means a continuous spectrum, but exhibits isolated lines of very short wave length in the neighbourhood of the region of atmospheric absorption. Before the war I used the Krohmeyer lamp in hospital practice, but without obtaining any very satisfactory results. Dr. Jansen, of Copenhagen, tells me that he has investigated the comparative results obtained in the treatment of lupus by the Finsen lamp and

by the mercury vapour arc, and that he found the latter by no means as efficacious as the former. He attributes the superior action of the carbon arc in the treatment of lupus to its richer yield of radiation in the longer and more penetrating wave lengths of the violet end of the ultra-violet spectrum.

Schunck, in a paper entitled 'A Spectroscopic Investigation of some sources of Ultra-violet Radiation in relation to treatment by Ultra-violet Rays', reported that the spectrum of the tungsten arc, and also the arc of wolfram (Simpson electrodes), 'consists of many lines of nearly equal intensity throughout the ultra-violet region, so close together as to form an almost continuous spectrum, extending with but slight loss of intensity to $\lambda$ 2,140 (the limit of the instrument employed)'. Schunck also remarked that the tungsten spectrum, and that from the Simpson electrodes, extended farther with the same amperage and exposure than that of any of the other sources that he examined; and among other sources he tested the following: molybdenum, iron, carbon, carbon rods impregnated by boiling in solutions of sodium tungstate, uranium nitrate, ammonium molybdate, and titanous chloride, and half-inch cored carbons filled with $U_3O_8$, $Fe_2O_3$, and wolfram and tungsten powder.

Now, since the main therapeutic effect of ultra-violet radiation is the result of the hyperaemia induced by exposure to the radiation, it follows that the intensity of the erythema and the readiness with which it is produced may be taken as a measure of the efficiency of the different sources of radiation.

Experiments conducted by Schunck on this basis, by exposing the flexor surface of his forearm to radiations derived from different sources, clearly showed that an erythema was far more readily and intensively induced by the tungsten and wolframite electrodes than by any other source of ultra-violet radiation.

The credit of the discovery of wolfram (the ore of tungsten) as a source of ultra-violet radiation belongs to

an electrical engineer, the late Mr. Simpson, who, it is stated, in the course of his investigations into the nature of the rarer ores, found that the hands of his workmen, suffering from eczema, became cured when exposed to the radiation of what were termed 'Simpson electrodes'. The composition of these electrodes was zealously guarded: the discovery, as is usual when therapeutic measures are introduced by those ignorant of the nature of diseases, was loudly boomed in the daily and the illustrated weekly press as a form of new X-ray, and extravagant claims were made for its curative properties in all kinds of diseases. Fortunately, instead of, as is far too commonly done by the medical profession, ignoring these claims and pronouncing them, untried, as quack discoveries, the properties of the Simpson electrodes were spectroscopically investigated by Professor Sidney Russ, and clinically by Dr. Sequeira: with the result that the identity of the electrodes with wolfram was spectroscopically proved, and their therapeutic properties were shown to be those of ultra-violet radiation.

These Simpson or wolfram electrodes burnt so unevenly in the electric arc and with so much spluttering and interruption that I obtained from the Thomson, Houston Co., of Rugby, some 'swaged' or highly compressed rods of pure tungsten, 0·25 inch square, which burn so evenly and satisfactorily that I still continue to use them in both my private and hospital practice. These rods are very highly compressed by a special process to enable them to be drawn out without fracture in the manufacture of the fine tungsten filaments for incandescent lamps. The high compression of the rods obtained in this way enables a current of 15 amperes to be passed through them without any spluttering taking place.

The other fittings needed are a nickel-plated concave reflector, to be held in the hand of the operator, by means of which he can at the same time protect his own face and adjust the focus of the radiation to the movements of the patient. A quartz lens, of about 4 inch focus, is also

needed; it should be mounted in a circular shield of light material to protect the untreated parts from the radiation. (It should be remembered in administering the treatment that the focus of ultra-violet radiation is slightly shorter than that of visible light.) Hooded glasses, of Crookes No. 4 glass, should be provided for the protection of the eyes of the patient, operator, and assistants.

A continuous current supply of at least 70 volts is needed to yield the required current of 15 amperes. The energy obtained from a current of 15 amperes enables far better results to be obtained than when employing lower current strengths.

The modern mercury vapour lamps are of many types, and their special features can be best ascertained by a study of the makers' catalogues. These lamps vary very much in the rapidity of their action; some of them are said to produce the requisite reaction in two or three minutes, whilst others require fifteen minutes to excite an equivalent erythema.

*A mercury vapour lamp should never be suspended directly over a patient; mercury, heated to volatilization, produces very serious burns if it falls or splashes on to the skin.**

The carbon arc usually takes the form of a standard or hanging lamp with one or more pairs of automatically fed carbons. If the voltage available is only 100 volts, only a pair of lamps can be used: but with a voltage of 200 volts, a triple arc arranged in series may be employed, thus securing a greater quantity of radiation at an equal cost.

### Choice of Lamp.

For use in a hospital ward, where the treatment will be administered by a nurse under the supervision of the Sister of the ward, the mercury quartz lamp is probably the most suitable instrument.

The carbon arc lamp of the hanging type is especially

* L'Assistance Publique de Paris has formally forbidden the practice of placing the patient directly under the burner of a mercury vapour lamp.

suitable for use for constitutional treatment in light departments and clinics, as several patients can sit round one lamp and can be attended to by one operator. The carbon arc is very slow in its action, but the time lost in its use is more than compensated for in hospital practice by treating three or four patients simultaneously, and, according to some theories of the therapeutic action of U.V.R., the longer wave length of the carbon arc may possess some advantages over the shorter wave length of tungsten and mercury radiation in constitutional treatments.

Both mercury vapour and the carbon arcs can be arranged to work on D.C. or A.C. They are both very simple to use, and, as they admit of no adjustment or variation of their voltage, the dosage depending solely on the square of the distance and on the duration of the exposure, their employment does not call for the same skill and experience that are required to get the best results from the tungsten arc, the voltage of which can be adjusted to the requirements of the case under treatment. For inexperienced workers the carbon and mercury vapour lamps are therefore the most suitable type of apparatus.

The tungsten hand-regulated arc lamp (see fig. 22) with a nickel-plated concave reflector, about twelve inches in diameter, separate from the lamp and fitted with a handle, is the best lamp for the treatment of local lesions, such as acne, alopecia, &c. To obtain the best results with this lamp considerable experience is required, and it is the best lamp for the expert worker.

The lamp should be fitted with an amperemeter and a regulating resistance, so that a suitable current for the case under treatment can be obtained and measured. In the treatment of local lesions the arc should be placed about six or twelve inches from the part to be treated, and, holding the reflector in his left hand, the operator should focus the radiation on the diseased area, at the same time shading his own face from the rays by means of the reflector. If, owing to the focussed heat rays, the part under treatment should become too hot, the reflector should be turned

aside for a few seconds. The reflected radiation should be concentrated in turn on the various affected areas.

The operator should wear goggles fitted with Crookes glass so that he can observe the changing colour of the skin during treatment.

By employing this technique, I find that the dosage can be regulated satisfactorily by the pink or red tint of the skin produced by the heat rays. This initial heat erythema appears to bear a definite relationship to the subsequent actinic erythema; for instance, it will be found that blondes, compared with brunettes, exhibit the same increased susceptibility to the heat rays as they exhibit to the actinic rays.

In actual practice, in all local treatments and in some general treatments, I judge the dosage entirely by this heat erythema.

In local treatments it is often necessary to produce an intensive reaction, and this can be judged with sufficient accuracy for practical purposes from the tint that the skin assumes. Initial trial doses are unnecessary with this technique, and the same amount of reaction can be elicited after pigmentation has occurred, for the appearance of the heat erythema is delayed in pigmented cases. With the mercury vapour lamps the absence of the heat rays and the green colour accompanying the radiation prevent the application of this regulating test.

Measurement of the dosage by means of pastilles or other appliances that merely register the amount of the radiation are of little use for practical purposes, as it is the susceptibility of the patient and not the amount of the radiation that we require to measure: for the former varies in different patients in the proportion of six to one, and the latter varies in only a simple and direct ratio.

A mercury vapour lamp in miniature has recently been introduced by M. Gallois, of Lyons. The idea was originally conceived by Professor Nogier, of Lyons, in 1911, but it was not until 1925 that M. Robert Gallois, unacquainted with the previous work of Nogier, constructed a mercury

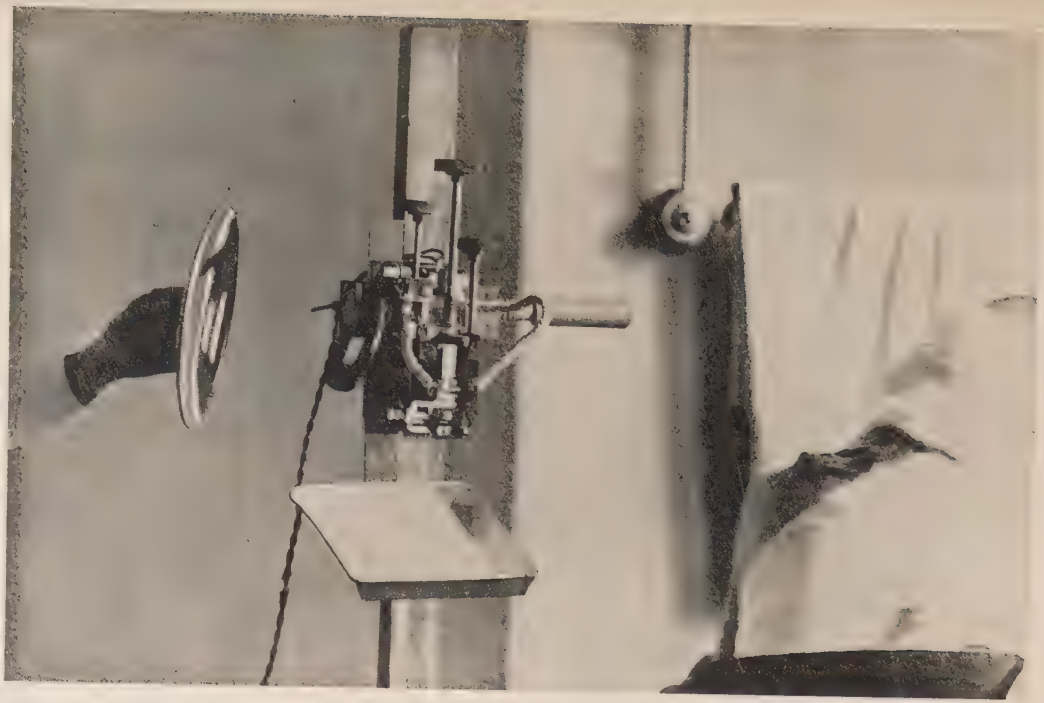


FIG. 22. This photograph shows an ordinary cinema or magic lantern arc lamp being used as a tungsten arc lamp with a hand reflector.

(The patient should be nearer the lamp than shown in this photograph, and his body should be more inclined to allow of the radiation falling on the wound at a right angle.)

vapour quartz electrode in the form of the H.F. vacuum electrodes of MacIntyre. These quartz electrodes are now manufactured by the firm of Gallois in all the shapes and forms of the MacIntyre electrodes. Quartz is substituted for glass in their construction, an internal tungsten wire is fitted, a globule of mercury inserted, and they are then filled with argon or neon gas to facilitate their illumination.

These electrodes are rather expensive, costing £5 or more in this country, but the toughness of the quartz is said to render them more durable than the brittle glass H.F. electrodes. The Gallois electrodes, when operated from a H.F. resonator or a diathermy apparatus give off a spectrum resembling that of the mercury vapour lamp; their radiation reaches to $\lambda$ 2377 A.U., and is specially rich at $\lambda$ 2536. This radiation quickly darkens photographic P.O.P., discharges a negatively charged electroscope, and excites fluorescence on a barium platino-cyanide screen.

### Precautions to be observed in the administration of U.V.R.

U.V.R. should be administered in only very small doses to very young infants.

Constitutional U.V.R. should be administered to aged and exhausted patients in very small doses.

Great care is necessary in its administration over areas in which the circulation is impaired, such as on oedematous legs and in cases of intermittent claudication.

Constitutional U.V.R. is contra-indicated in cases of active pulmonary tuberculosis.

In an exhaustive paper dealing with the accidents associated with the administration of U.V.R., Jaulin remarks (6) that the relation of cause and effect has not been established in any of the published cases of death occurring after the administration of U.V.R.

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## CHAPTER III

## THE THERAPEUTIC ACTION OF X-RAYS

RADIOTHERAPY, or the treatment of disease by X-rays, forms an integral part of the province of the electrotherapist; and its development in the past has been considerably hindered by its too exclusive association with the work of the radiographer. During the Great War the resources of radiotherapy were not utilized to anything like their full extent, owing to an idea, prevalent with the authorities, that its administration should rest solely in the hands of the radiographic expert. Apart from the fundamental identity of the instruments employed, there is little in common between the sciences of radiography and radiotherapy; the type of instruments suitable for the former becomes more and more unsuitable for the latter, and vice versa, as the two sciences mutually develop.

Moreover, as the result of the urgent and immediate nature of the demand for radiography during the war, the radiographers had no time at their disposal for radiotherapy, which consequently remained in almost complete abeyance, and nearly all our knowledge of its action in the resolution of scar-tissue, in the treatment of nerve injuries, &c., is derived from the investigations of French workers.

On the other hand, treatment by X-rays is so intimately associated with other forms of electrical treatment that no electrotherapist can afford to overlook or remain ignorant of the science and practice of radiotherapy. Many of the diseases amenable to X-rays and other forms of electrical treatment exhibit symptoms which at one time will call for the one form of treatment and at another time will be best met with the other. The electrotherapist, who is acquainted with and experienced in both methods, will alone be able to predict which of the two, under certain circumstances, will be the more likely to ameliorate the symptoms, or effect a cure. The truth of this is seen in the treatment of such divergent conditions as acne and sciatica.

### The Action of X-Rays

The Coolidge tube so far exceeds in therapeutic efficiency any other tube in general use in this country that its action will be chiefly considered.

When the tungsten filament attached to the kathode of the Coolidge tube is electrically heated by the heating circuit, electrons are thrown out from it in proportion to the degree of heating. The exhaustion of this tube is, in its manufacture, carried to such a high degree that, until such electrons are emitted from the kathode, there are no ions or electrons to carry the current from the kathode to the antikathode.

The number of electrons emitted from the antikathode will depend upon the degree to which it is heated, and the amount of current carried across the tube with a given voltage will vary proportionately; conversely the lower the heating current, the higher will be the voltage required to force a current through the tube. That is to say, as the heating current is decreased, the potential from the source of supply, induction coil, static machine, or transformer, or whatever source is employed, must be increased; consequently the energy of the electrons, or the force with which they are hurtled against the antikathode, is correspondingly increased. Upon the energy with which the electrons impinge upon the antikathode, the frequency of the resulting X-rays will depend. The greater this energy, the higher will be the frequency of the radiation to which the electrons emitted from the antikathode will give rise, namely, the harder and the more penetrating will this radiation become.

We are thus able, when employing the Coolidge tube, by increasing the subsidiary heating current, the potential of the main source of supply remaining the same, to increase the milliamperage passing through the tube, at the same time producing softer and less penetrating radiation. Or by increasing the potential of the main supply, the heating current remaining the same, the current passing

through the tube is lessened; but the hardness or penetration of the resulting radiation is increased.

The antikathode of the X-ray tube may be regarded as a transformer which converts the energy of the electron hurled against it from the kathode into X-rays, and the greater the potential of the source of supply, the greater will be the energy or hardness of the resulting radiation. But, though all the electrons from the kathode may strike the antikathode with equal energy, the resulting radiation will not be homogeneous (namely, all the rays will not have a similar degree of frequency). For those electrons which are shot off from the surface of the antikathode will have lost none of their energy, and will excite a radiation of the maximum frequency and hardness: whilst the electrons emerging from a short distance below the surface of the antikathode will have lost some of their energy in forcing their way to the surface, and will consequently give rise to a radiation of longer wave length, of lower frequency, and of less hardness. Consequently the emanation of radiation from the antikathode, resulting from the energy of the electrons striking it, whatever their energy may be, will be heterogeneous. That is to say, the radiation will consist of a widely varying range of frequency or hardness, the upper limit of such radiation being dependent upon the energy imparted to the electrons shot off from the kathode by the potential of the source of supply.

The X-rays, excited by the discharge of electrons from the antikathode of the X-ray tube, reproduce the mechanism of their own production upon the material or substance upon which they fall, discharging electrons or soft $\beta$-rays from them by the resonant agitation which they set up. If the material upon which the X-rays fall contains no element with an atomic weight greater than 40, what have been termed 'scattered rays' are produced: but if the X-rays fall upon an element with an atomic weight greater than 40, 'secondary radiation' is excited. In this latter case the X-rays falling upon a substance with the

higher atomic weight discharge electrons from it with such energy that they in turn excite secondary radiation, the type of which varies with the nature of the material upon which the X-rays fall, the type of secondary radiation emanating from silver differing widely from that derived from aluminium, and so on.

As light has no action upon any body upon which it falls, unless some absorption takes place, so X-rays are said to have no action upon any substance unless the rays are absorbed, scattered, or transformed. This practically amounts to the same thing, for in all these processes there must be some absorption of energy.

In discussing the action of U.V.R. we have already seen that X-rays excite a resonant agitation in the atomic electrons in close proximity to the nucleus, whilst U.V.R. activates the atomic electrons in the outer concentric rings of the atomic orbit; and, since the resulting chemical changes are far greater when the electrons near the nucleus are acted upon, hence the chemical effects resulting from X-rays are far greater than those set up by U.V.R. Again, the effects of X-rays, which are capable of passing through any part of the body with a varying loss of energy, must be incomparably greater than the effects of U.V.R. which are totally absorbed at a depth of a small fraction of a millimetre.

### The Therapeutic Action of X-Rays

From the foregoing brief *résumé*, adapted from the writings of the leading authorities, of the physical nature and action of X-rays, it will be seen that their fundamental action is the discharge of electrons from the bodies upon which they fall. Such an action we have already seen to be the characteristic of ultra-violet radiation; but, in the case of X-rays, the energy is so much greater that the electrons are emitted with such force that they themselves are capable of exciting radiations, the nature of which depends upon the nature of the substance upon which the X-rays fall.

The effect of secondary radiation is well shown by the so-called 'X-ray burns' of the skin, which have occurred when a metal filter has been applied, during the administration of X-rays, direct to the skin of a patient without the interposition of any absorbing medium such as chamois leather; the soft and readily absorbed secondary radiations, in such cases, cause a 'burn' of the skin. An instance of such an X-ray burn from secondary radiation has been recorded by a radiologist, who himself received such an X-ray burn from the secondary radiations excited by the metal of a wrist watch during the course of X-ray administration.

We have attempted to show that ultra-violet radiation has a selective action on the chromatin of the nucleus of the cells, when the metabolic activity of the cell is at its maximum in the process of division, splitting it up and thereby possibly setting free a product, which, varying with the intensity of the radiation, has a destructive effect on the surrounding tissues. Such a hypothesis as this is in full accord with the views propounded in a very valuable and suggestive paper, entitled 'Fondements rationnels, Indications techniques et Résultats généraux de la Radiothérapie des Cancers', by Dr. Claude Regaud (1), Director of the Biological Laboratory of the Paris Radium Institute.

In this paper Dr. Regaud discusses the subject from the point of view of the surgeon, and commences by pointing out that the view generally held by surgeons that X-rays act, and should act, on cancerous growths in the manner of a caustic is a wrong one. The error doubtless originated in the first place, and in the past was justified, when unfiltered—that is, too soft—X-rays, of little penetrating power and easily absorbable radiations, were employed. The main object of the paper is to urge the employment of the selective cytocaustic ('sélective cytocaustique') action of very hard X-rays and the very penetrating gamma rays of radium. He states that certain cells are peculiarly radio-sensitive to hard X-rays administered in a suitable dosage. 'For example, it is possible to cause

the disappearance, completely and definitely, of a subcutaneous tumour, such as a 'globo-' or lympho-sarcoma, by radiation filtered through 7 to 8 mm. of aluminium, without the skin presenting any other change beyond, perhaps, sometimes the falling out of the hair or beard. This cytocaustic action clearly shows the selective action of the rays on two types of cells, i.e. the cells peculiar to the sarcoma, and the generating cells of the hair follicles.'

Dr. Regaud argues that, from the point of view of their receptivity, there is a very extended range of difference between the more sensitive cells, such as those of the sexual organs and the leucocytic glands, and the far less sensitive cells of structures such as nerves and muscles, and that this variation in receptivity is to a large extent analogous to the selective action of specific drugs, such as the action of digitalis, curare, or the tetanic toxin on certain cells. This radio-sensibility is not, however, the special property of any type of cell; but is 'inherent in certain states, or physiological moments in the life of the cell, the most important and the best known of which is the state of reproduction'. Cells which are preparing for division, cells undergoing division with short intervals of rest, cells exercising a secretory function, are specially sensitive, the period of greatest radio-sensibility corresponding to the maximum metabolic activity of the nucleus. The period of maximum metabolic activity is a short one, consequently the period of maximum radio-sensibility is also a brief one. The special radio-sensibility of cancer cells is due to their indefinite reproduction.

'Since then hard X-rays and gamma radiations are poisons antagonistic to cellular reproduction, from this very fact they become curative agents of cancer. Experience has actually shown that a malignant tumour, well localized and suitably situated for radiation, can be completely and absolutely dispersed.'

There is a very wide range of radio-sensibility, and though every malignant tumour is more radio-sensitive than the surrounding tissues and the tissues which it

penetrates, nevertheless there is a very wide difference in the radio-sensibility of different neoplasms. The most radio-sensitive of malignant growths are the lympho-sarcomata, and the least sensitive are the epidermal epitheliomata. Between the radio-sensibility of the latter type of malignant growth and that of the normal tissues the difference is only slight, and consequently the radio-therapy of such growths is not unattended with danger.

Dr. Regaud emphasizes the fact that his remarks only apply when hard X-rays or gamma radiations are employed. 'The action of hard X-rays or gamma rays thus brings about, more or less rapidly, the death of the cells. A less sensitive cell is chiefly affected in its power of reproduction: this may perhaps be impaired for a time; or if the cell continues to divide, the descendants are affected by malformation and degeneracy, which brings about their death after some generations.' This result, Regaud points out, is due to the ascertained fact that hard X-rays and gamma radiations are the selective poisons of the nuclear chromatin, 'which, as every one knows, is the support of heredity. It is this that the radiations suppress or suspend in the reproductive cellular tissue.'

If, as Dr. Regaud points out, the real selective action of hard X-rays and gamma radiation is upon the chromatin of the nuclei of the cells in a state of division, an important line of research is opened up to ascertain by what means the maximum number of cells of the tissues to be destroyed may be brought to the most active state of nuclear division at the time the radiation is applied. In this connexion, some observations, which I first made in 1919, may be of interest. After treating some cases of acne of the face by intensive ultra-violet radiation from the tungsten arc,I found that in some instances the thickened acne nodules had not completely resolved. To effect their resolution, I applied $\frac{1}{2}$ and $\frac{2}{5}$ pastille doses filtered through $\frac{1}{2}$ mm. of aluminium. I was surprised, and at first rather alarmed, to find that I obtained a definite X-ray erythema with even these small doses. I subsequently reported this

occurrence to two well-known radiologists: the first was rather an alarmist, and remarked that he did not like these erythemata; he had so often seen telangiectases follow them after many years. Fortunately the erythema so produced was mild in character, of short duration, and unattended by any untoward symptoms, so my mind was soon at rest. The other radiologist had experienced the same result, and exclaimed enthusiastically, and quite correctly: 'But don't such cases do well?'

The explanation, in accordance with the theory of Dr. Regaud, that naturally suggests itself, is that the superficial cells were in a peculiarly radio-sensitive state, due to the active cell division resulting from the previous erythema, excited by the intensive ultra-violet radiation. If such a conclusion is correct, we have in ultra-violet radiation a ready means for exciting an increased radio-sensibility of the superficial tissues, and if it were possible to devise a means of increasing to a similar extent the radio-sensitiveness of the deeply seated neoplastic cells, we should have gone a long way towards the solution of the problem of the cure of cancer by radiotherapy.

Until the past few years there was a general consensus of opinion among radiotherapists that the harder the X-rays the better would be the results obtained. This view, which was largely responsible for the introduction of the intensive Erlangen method of Wintz, in part originated from the results obtained in the treatment of malignant growths from the application of radium. But the better results obtained in certain cases from the gamma rays of radium appear to be due to the fact that the radium application can under certain conditions be placed in direct contact with the growth to be destroyed, rather than to the shortness or hardness of its radiation. It is upon the proportion of the radiation which is absorbed that the biological effects depend, and, consequently, the penetrating power of the radiation should be adjusted to the depth at which its action is desired and the nature of the structures through which the radiation has to pass.

Radiotherapy may be classified in three divisions:—

1. The single massive dose, as administered in the technique of Wintz and others. The term 'deep therapy' often applied to this method is a bad one, as other methods involving much smaller dosage can also be deeply applied.

2. The moderate dose of about 4/5 of a pastille.

3. The fractional spaced dose, amounting usually to about 1/6 of a pastille.

The first of these methods does not fall within the scope of the electrotherapist's work. The high cost of the necessary apparatus, the time and special knowledge required for its application make it a speciality of its own. The moderate dose and the fractional spaced dose should, however, form part of the electrotherapist's work. The former of these two methods is required for the production of the menopause, the treatment of Graves' disease; and the latter, the fractional spaced dose, falls especially within the sphere of the electrotherapist for the treatment of certain forms of sciatica and brachial neuritis.

The trend of modern development in radiotherapy appears to be along the path of small spaced doses, and the intensive method of the Erlangen school seems to be losing ground.

A few years ago, the electrotherapist, who only possessed an X-ray plant of moderate power, felt doubtful, in view of the pronouncements of the Erlangen school, whether he ought to undertake the prophylactic treatment of carcinoma of the breast for fear that he might stimulate rather than destroy the latent cancer cells. The view that cancer cells are stimulated by small doses of X-rays seems now to have been abandoned by the leading authorities. Holzknecht, in a paper contributed to an American journal (2), expresses himself very forcibly on this point: 'During the last ten years it seemed that Röntgen irradiation of carcinoma was about to reach the acme of success, thanks to advances in physics and technique, but since 1921 decisive changes have taken place which do not lead towards improvement, and radiologists have experienced keen dis-

appointment in seeing their high hopes shattered. All the supposed improvements have had to be abandoned, and the basis for the work revised. Doubt was cast on the methods employed because the basic principles were not well founded. The errors which were made, were, however, not without benefit, for truth can be established only after mistakes are recognized as such.

'It was a grave error to suppose that all carcinomas react in the same manner to X-rays; even those histologically alike have different reactions. It has also been established that the rays applied in small doses do not stimulate growth as was formerly supposed, but they do have as strong an effect as larger doses. Extremely strong doses, on the other hand, are less effective.'

From experiments performed on the action of X-rays on pumpkin seeds, Guilleminot found that the effects of the irradiation on the subsequent germination and growth of the plants were the same whether the X-rays were applied in a single massive dose, or whether a similar dose was applied divided into several fractional doses administered at weekly intervals. That is to say that, when administered in small fractional spaced doses, there was a cumulative effect, without loss, on the cells of the seeds which were in a state of 'latent life'.

These results have been confirmed by Otto Jüngling and other workers experimenting on the seeds of various plants.

Cells of the skin and skin epitheliomata, which are in an active state of life and are continually undergoing renewal, do not accumulate the fractional doses without loss, and consequently the cumulative effect upon them is not so great as upon the cells in a latent state of life.

It would, perhaps, be more correct to speak of an accumulation of the effect rather than an accumulation of dose, for it is the effect and not the dose that is cumulative.

The ideal method of destroying all the neoplastic cells by a single massive dose can only be realized with the most sensitive of lymphosarcomata and such other malignant growths as are of very high radio-sensibility.

In less radio-sensitive neoplasms, the cells which are not in the maximum stage of radio-sensibility, namely those cells which are not in process of mitosis, are not killed by this single dose, but remain latent until at a later date, becoming active, they lead to a recurrence of the growth.

With the small spaced dose these latent neoplastic cells receive an accumulated dose, without loss, that considerably exceeds in amount the single massive dose. Otto Jüngling illustrates the practical value of this theory by the following example of the action of the moderate spaced dose in the prophylactic post-operative treatment of cancer of the breast. If we give only 4/5 of a pastille dose on the surface of the part irradiated, we can repeat this dose every month during the first year, and every second month during the second year, thus giving in the two years a total of eighteen doses without producing any injury to the skin. During this period of two years, the latent neoplastic cells, although at each treatment they only receive a fractional dose, accumulate a dose, without loss, at least nine times greater than it would be possible to administer to them at a single treatment. (3)

The fractional spaced doses of 1/6 of a pastille specially concern the electrotherapist, for it is the action of these small doses, in leading to the resolution of newly formed fibrous tissue and in inhibiting cellular proliferation, that is of such value in many cases of sciatica and brachial neuritis, and in the early stages of infantile paralysis.

This form of treatment is of special value in association with diathermy: it is customary to speak of the action of each of these methods as one of 'decompression', though it is clear that the manner in which the pressure is reduced in the two cases is of a very different character.

In the case of radiotherapy the relief of pressure is due to cellular destruction and a diminished cellular production; in the case of diathermy it is the result of an improved drainage of the tissues facilitated by the dilatation of the efferent channels brought about by the heat, and possibly

aided by an ionic perturbation. Theoretically, therefore, the two methods should be mutually helpful.

For the requirements of the electrotherapist a powerful X-ray coil capable of yielding a 15-inch spark from point to plate will be found more suitable than a powerful interrupterless transformer.

For the treatment of the early stages of infantile paralysis a spark gap of 15 inches may be required, but most of the requirements of the electrotherapist will be met by a spark gap not exceeding 10 inches.

It is in the old-standing cases of sciatica and brachial neuritis, where the pain is due to the involvement of the nerve trunks in newly formed fibrous tissue, that the electrotherapist will find radiotherapy an indispensable adjunct to his other methods of treatment. In dealing with these painful lesions, the method of treatment has so frequently to be changed to meet the varying conditions that it is impossible for the electrotherapist to obtain the best results unless he has all the necessary instruments at his disposal. It is for this reason that the electrotherapist is especially concerned with the administration of the fractional dose, and unless its application is undertaken by him but little progress will be made in our knowledge of the benefits to be derived from its use in the class of case to which reference has been made.

The recent advances in radiotherapy, especially in relation to the spaced fractional dose, are the outcome of the work of Regaud on the increased radio-sensibility of the cell during the process of mitosis.

When we take a wide view of the action of the short wave lengths we cannot fail to be struck by the many points in common between U.V.R. and X-rays, but the point that especially attracts our attention is the selective action of both these radiations upon the nuclear chromatin, and it is from further investigation of the nature of this action that our knowledge of the fundamental action of U.V.R. and X-ray treatment will probably be obtained.

### Super-soft X-rays, or the Border-line or "Grenz" Rays of Bucky.

Recently a type of radiation intermediate between U.V.R. and X-rays, but approximating more closely to the latter, has attracted considerable attention in America and Germany, and has been applied to the treatment of various skin diseases.

Bucky (4) describes these super-soft X-rays as 'electromagnetic oscillations (infra-roentgen rays) of a wave length of about 1·5 to 2 Ångstrom units. They are characterized by their small penetration power, so that almost all of their energy is absorbed by the tissues, e. g., skin of about 2 mm. thickness.'

Eller and Anderson (5) describe the difference in biological action between these soft and the harder X-rays as follows: 'the super-soft rays may produce an erythema instantaneously; the pigmentation which follows its use is greater; with marked erythema doses no epilation occurs; pin-point vesicles and larger ones may appear following double erythema doses; the penetration is very much less and a very early leucocyte drop occurs with a rapid return to normal. Super-soft roentgen rays simulate the ordinary roentgen rays in that they both have latent erythemas; each may have pain following marked erythema doses; and both are cumulative in effect. Latent erythemas of from two to four weeks have been observed with this super-soft radiation.'

About thirty different kinds of skin disease have been treated by these super-soft X-rays. The results, however, do not, so far as can be gathered from the reports, show any striking improvement on the results obtained from intensive treatment by U.V.R. or from the usual X-ray technique; except, perhaps, in the treatment of epitheliomata of the eyelids. Of this condition 'several cases have been cured with this therapy', Eller. (6)

In an interesting and exhaustive paper on this type of radiation, Eller (7) arrives at the following conclusions:

'1. Electromagnetic vibrations of 2 Ångstrom units in wave length are very soft X-rays.

2. These rays have all the properties of roentgen rays.

3. With a voltage of 8 kv. or less no sequelae have been observed after two years. Therefore the rays can be employed with a greater degree of safety than ordinary roentgen rays.

4. Many skin diseases have responded quite favourably to treatment with these rays, particularly epitheliomas of the eyelids.

5. In the writer's opinion these rays will ultimately find an important though limited place in the armamentarium of the dermatologist.

6. The writer does not feel that super-soft roentgen rays (2Å) will replace the usual roentgen rays in the treatment of skin diseases.'

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# PART IV

# ELECTRO-PATHOLOGY

## CHAPTER I

## ELECTRICAL ACCIDENTS

ELECTRICAL shock may directly cause death in one of two ways, namely, by inhibition of respiration, or by causing a tremulation of the heart, fibrillation.

Of these the former is by far the more common; it is also more amenable to treatment, provided that treatment is immediately adopted.

Inhibition of respiration is due to the stimulation of the inhibitory action of the vagus by the sudden concentration of hydrogen or hydroxyl ions that passes as a progressive wave of hydrogen ionic concentration through the tissues from the negative pole to the positive pole at the make of current, and as a wave of hydroxyl ion concentration from the positive to the negative pole at the break of the current.

In the case of the constant current there is only one such concentration at make and another at break; but in the case of the alternating current these ionic concentrations occur with a frequency corresponding to the periodicity of the alternations of the current. It is for this reason that the alternating current is far more dangerous than a constant current of similar voltage.

With a current of very high tension, 1,200 volts and upwards, death results from respiratory inhibition. With currents of lower voltage, 120 volts or even lower, death may result from the tremulations (fibrillation) set up in the ventricles.

D'Arsonval (1) stated that the only danger from the constant current occurred at its make and break, and this statement is in full accordance with what we should predict from the theory of ionic concentration. On the other hand, Prévost and Batelli (2) experimented with currents

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of 550 volts from a D.C. dynamo controlled by a liquid resistance, by means of which they were enabled to turn the current on and off so gradually as to avoid the possibility of any make or break shock. Nevertheless, this strong current induced fibrillation of the ventricles of the heart. This paradoxical result is explained by the fact that no D.C. dynamo yields a true constant current, for in all currents so obtained there are fluctuations of strength inseparable from this method of production. By listening with a telephone receiver to such a current very distinct ticks corresponding to these irregularities can be heard clearly. The employment of a liquid in place of a wire wound resistance does not suppress these irregularities, but would merely prevent their effects from being increased by inductance.

These irregularities of the current strength are necessarily accompanied by variation in the ionic concentration along the lines of force through the tissues; and such a current of 500 volts applied to a dog, head to tail, with the heart in the direct path of the current, as was the case in these experiments, would be quite adequate to produce sufficient variation of ionic concentration, acting upon the very sensitive nervous mechanism of the heart, to set up ventricular fibrillation. To have been conclusive the current for these experiments should have been derived from accumulators or dry cells, when, doubtless, the results would have been very different.

Low tension constant currents, even when derived from D.C. dynamos, are not sufficiently strong to cause fibrillation without the make and break shock; but with the break shock a current of 50 volts is sufficient to kill a dog if administered head to tail. Alternating currents of a tension as low as 10 volts can set up fibrillation in a dog's heart.

It would appear that the current, provided it is of sufficiently high voltage, causes apparent death immediately by the inhibition of respiration, that is to say, before there is time for the establishment of fibrillation. But, provided

that the voltage is insufficient to effect this sudden inhibition of the respiratory centre, the danger is not over, for cardiac fibrillation may be set up, the efficient treatment of which is far more difficult than of the suspension of respiration. So that, as d'Halluin points out, we arrive at the paradox that currents of moderate or even low voltage may be even more dangerous than those of very high tension.

In 1890, electrocution as a form of capital punishment was introduced into New York State. At first a voltage of 1,500, with a periodicity of 15 to 30, was employed. It was found that, though respiration was inhibited and sensibiiity abolished almost immediately, yet the heart continued to beat, and, when additional shocks were not administered, respiration was in some cases restored. Therefore, in order to make assurance doubly sure, a new technique was adopted in 1899: a current of 1,500 to 2,000 volts was applied for 7 seconds, then a current of 200 to 400 volts for 30 seconds, and finally a current of 200 volts for a few seconds. In this way a respiratory inhibition was primarily secured, and was followed by a fibrillation of the ventricles, due to the lower tension, and in this manner a fatal result was ensured. In two cases an immediate autopsy was performed and revealed to view a rhythmical contraction of the auricles with the ventricles in a state of fibrillation.

The diagnostic differentiation of electrocution by respiratory inhibition from electrocution by cardiac fibrillation is clearly of some importance, for the treatment of the two conditions is essentially different. It is not, however, so important as at first sight might appear, for the methods involved in the treatment of ventricular fibrillation are so complicated, need such special skill in their application, require drugs that in the case of emergency are not likely to be at hand, and above all, are so ineffective in their action, that in all ordinary cases it is best to give the patient the benefit of the doubt and act on the assumption that the apparent death is due to inhibition of respiration.

In industrial accidents these cases of apparent death

from electrical shock are usually brought about by brief contact with very high voltage, such as the 60,000 volts of a trolley system, or the 1,000 or 10,000 volts of a power transmission. In these cases respiratory inhibition occurs before cardiac fibrillation is established, and in many of these cases, provided that artificial respiration is *immediately* resorted to, life may be restored.

It is exceedingly regrettable that this fact is not more widely recognized, for many lives have been sacrificed owing to the loss of vital time before resorting to artificial respiration. I can recall to mind two such cases that have been reported recently in the general press. In the one case the brass helmet of a fireman came in contact with a live wire. The fireman, who was apparently killed by the shock he received, was at once, without receiving any immediate treatment, taken off to a hospital, where, after the delay necessitated by his transport, a further delay in securing his admission, and a still further delay in obtaining the services of the resident medical officer, artificial respiration was commenced with no result as the apparent had passed by this time into real death. Delays of a similar nature occurred in the case of a stoker on an underground railway, whose pickaxe had come in contact with an overhead trolley wire, and naturally a similar fatal result occurred as the consequence of these delays.

Now, in both these cases, skilled aid was immediately available on the spot at which the accidents occurred; for both the members of the fire brigade and the railwaymen are trained in the methods of artificial respiration. In all probability both these deaths are attributable to ignorance of the fact, which Professor Jellinek has pointed out, that death from electrical shock is nearly always at first only apparent death, and that the patient can be restored to life provided that artificial respiration is immediately resorted to.

It is essential that artificial respiration should be begun immediately, and that it should be continued for at least four hours. 'Recovery is common after three hours and

has occurred after eight hours'. (3) Artificial respiration should be mainly relied upon; but, if the heart has ceased to beat, cardiac massage, either by the abdominal or thoracic method, may be practised. The cessation of the heart's beat may be recognized in some cases by the absence of the pulse and the disappearance of the heart sounds. D'Halluin has suggested a more positive test by placing a drop of ether in one eye. If the heart has ceased to beat, the ether will occasion no suffusion of the eyeball; but, if it still beats, a slight redness will immediately occur, and can be confirmed by contrasting the redness of the treated eye with the pallor of the untreated eyeball.

The treatment of fibrillation of the heart muscle is most discouraging. A current of 1,500 to 4,000 volts may restore rhythmical contraction to the tremulating ventricles of a dog, or an alternating current of about 240 volts applied directly to the dog's heart may bring about a similar result; but these procedures are too heroic for practical adoption.

Maurice d'Halluin (4), as the results of experiments on fibrillation in dogs, has found that the fibrillation, excited either by massage of the heart or by its electrical stimulation, can be immediately arrested by the intra-venous injection of 5 per cent. solution of chlorate of potash, 4 c.c. of this solution being injected for each kilogramme of the animal.

The chlorate of potash is toxic to cardiac muscle and arrests the heart beat, but rhythmic contraction of the heart muscle can be restored by massage of the heart for from five to ten minutes. So desperate is the prognosis in cardiac fibrillation and so ineffective are the other remedies, that d'Halluin suggests a similar intra-venous injection in cases of fibrillation in man. In this case he suggests a dose relatively smaller than in the dog, and regulated by the volume of the heart rather than by the body weight. The rate of the intra-venous injection largely influences the toxic influence of the drug. D'Halluin found that no trouble was experienced, in the case of dogs, by injecting

30 or even 42 centigrammes per kilogramme weight of dog at a rate of 4 to 6 milligrammes a minute: but that 35 centigrammes per kilogramme was fatal with an injection rate of 11 milligrammes per kilogramme a minute.

So far this drastic remedy does not appear to have been applied to man, and it is highly improbable that the prepared solutions of the required strength and the necessary appliances would be available at the hour of need. These experiments consequently possess an academic rather than a practical value.

Electrical shocks of the severity described above are practically unknown in the practice of electrotherapy. With the high voltages necessary for deep X-ray therapy there is danger of contact with a high tension wire and a short to earth through the patient. Great care is consequently indicated to secure the firm fixation out of reach of the patient and operator of wires carrying such voltages. Fatal accidents have been recorded from the X-ray operator coming in contact with such wires.

The only real danger of a patient receiving a fatal shock from high voltage current during electrical treatment is when he is being treated by the now nearly obsolete electric bath, for this form of treatment both on account of its ineffectiveness and its danger has been entirely abandoned except perhaps in the old-fashioned electrical departments of one or two hydros.

In the three-wire system of wiring the generating dynamos at the supply station one of the wires is earthed.

If a person in an ordinary bath makes good contact with the pole of the supply opposite to that which is grounded at the supply station, he completes the circuit through his body back to the generator through the earthed water pipes of the bath, and so receives the full voltage of the supply, possibly with a fatal result. Accidents of a similar nature can occur through the earth wire of a radio receiving set. In this case the listener-in may be in good contact with earth through this wire, and by coming also in contact with the opposite pole of an electric reading

lamp or some other connexion with main supply current, he may receive the full force of the supply current from the main by completing the circuit through his body and may so be killed.

These examples illustrate the necessity for a patient being carefully insulated whilst under electrical treatment from any radiator or other good connexion with the earth; for, whilst he is in such contact, a serious shock may be received from the pole of the apparatus opposite to that which is earthed at the supply station.

Provided that the usual simple precautions are taken there is no danger of such accidents occurring during the course of an electrical treatment, and this is evidenced by the fact that, notwithstanding the thousands of electrical treatments that are daily administered by both skilled and unskilled workers, we practically never hear of the occurrence of such accidents.

The following are the chief precautions to take:

1. The patient during his treatment should be so placed that he is not within reach of any water pipe, gas or electric fitting, that has a direct contact with earth. Some electrical departments have a stone or cement floor; if such is the case, linoleum sheets or wooden platforms should be interposed to cut off earth contact, or the patients should be treated on couches with wooden legs, or by means of Schnee's baths. Too much reliance must not be placed on the insulation from earth of linoleum or wooden floors, as these are apt to become wet during the course of electrical treatments and so become deprived of their insulating protection.

2. Neither the operator nor patient should touch a water pipe, radiator or gas pipe whilst touching or in contact with a switch-board or an electrode.

3. The electric bath should never be employed.

4. All high-tension wires should be securely fixed, and so arranged that in no case can they fall on a patient, and their condition and the state of their fixation be periodically examined.

5. Interrupted currents of low frequency should never be employed in the region of the heart.

Though I have never come across any accidents of the nature dealt with above, I have nevertheless encountered two alarming incidents of a totally different causation.

The first occurred some fifteen years ago in the early days of my electrical work, and was of a most alarming character. The patient was a Rhodes scholar, a healthy, well developed and athletic young man, with slight rheumatic pains in his legs and feet. I was administering a constant current of only very small milliamperage from a pantostat through his legs and feet by means of Schnee baths. Suddenly, without any warning, he threw his head back, in so doing breaking a window pane in front of which he was sitting, and fell on the floor. He was completely pulseless, his respiration had ceased, his pupils were fully dilated and flattened on pressure. I at once commenced artificial respiration and, to my great relief, breathing was soon restored and the pulse re-established.

The patient was rather bewildered after his attack but otherwise more or less normal. I took him home to his college, saw him into bed, and the next morning found him completely recovered and suffering from no after-effects. The patient appeared to think very little of the occurrence and volunteered the information that, though his heart had always been found quite sound and his general health was good, he was subject to severe fainting attacks for which no cause could be assigned. This attack appears to have been psychical rather than physical; previous to its onset we had been discussing Leduc's experiments on the electrical introduction of strychnine into rabbits. Whether such a conversation had any suggestive causation on his attack is for the psycho-analysts to determine.

The only other alarming incident that has occurred in my own practice is of value as a warning to others as well as to myself, and it is for that reason that I mention it. A lady came to me for diathermic treatment of a rheumatic knee. On her second or third visit she was receiving 1·5

amperes through the affected joint; she had received one or two previous treatments at a similar intensity of current without the slightest inconvenience. She was perfectly comfortable and I had left her under the charge of the nurse for a few minutes, when I was urgently recalled, and found the patient almost pulseless, very pallid and collapsed. Her condition was most alarming and it was nearly an hour before she was sufficiently recovered to be moved home. The patient afterwards told me that she had undergone a very severe and prolonged medical examination in the morning, which had so fatigued her that she was nearly putting off her visit to me. It would appear that even the very small diathermic current which she received so lowered her blood pressure that owing to her exhausted condition it produced the alarming symptoms that I have narrated. This case illustrates the reduction of blood pressure by diathermy and the caution with which such reduction must be brought about in debilitated patients.

The treatment for collapse of this kind is the hypodermic injection of strychnine and the inhalation of ammonia.

Incidents such as these are fortunately of rare occurrence in electrotherapy, but the mere possibility of their occurrence emphasizes the importance of having a medical man in attendance during the administration of electrical treatment.

Unpleasant and dangerous shocks may arise from badly designed instruments of high tension. There is one type of diathermy instrument, for instance, in which a powerful induction coil charges condensers of large capacity which in turn discharge across a multiple spark gap. In shunt with the patient, when receiving diathermy, there is a detachable D'Arsonval solenoid. Combined with the apparatus there is an Oudin resonator for use when administering high-tension high-frequency, and in this case the D'Arsonval solenoid is removed. There is a danger with this apparatus, if the D'Arsonval solenoid, after its removal for the administration of the H.T. current is

not replaced before the patient is attached to the diathermy terminals. In such a case the patient would receive a discharge from condensers of large capacity charged at very high potential by a 12 or 16 inch coil, as the case might be, and would experience a most unpleasant if not dangerous shock.

An apparatus designed on such lines is not to be recommended for diathermy, and, if it is used, the greatest care and caution should be exercised in its employment.

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# PART V

# ELECTRO-DIAGNOSIS

## CHAPTER I

## THE ELECTRO-DIAGNOSIS OF PERIPHERAL NERVE LESIONS

DURING the late war the electro-diagnosis of peripheral nerve lesions formed an exceedingly important and interesting part of the work of the electrotherapist. It should always be borne in mind that this method forms only one of the links in the chain of evidence by which peripheral nerve lesions are detected; and, though it is one of the most important links, it must invariably be connected with the other clinical methods in the examination of a wounded limb; such as careful inspection of the limb to ascertain the nature, situation, and direction of all the wounds; observation of the temperature of the limb, the condition of the circulation and the nutrition of the skin, and the power of voluntary movement in the muscles; palpation of the muscle tone; and, above all, the examination for the presence or absence of *fourmillement*.

*Fourmillement* is that sensation of tingling or of pins and needles which is experienced by a patient in the peripheral distribution of a nerve when digital pressure is applied to the trunk below the seat of injury. Two precautions are necessary in eliciting this sign: the pressure must be applied below the lesion and not on the scar; the application must be such a distance below the scar that it can exercise no traction upon it. No leading questions must be put to the patient to suggest the nature of the sensation which he may feel, but, applying pressure at a suitable point, the examiner should merely ask the patient, 'Do you feel anything?' If he merely replies that he feels the pressure of the doctor's fingers, the evidence is negative.

If, on the other hand, he replies that he feels a sensation like an electric shock, &c., down his fingers or toes, as the case may be, and if the sensation corresponds with the anatomical distribution of the particular nerve trunk under examination, it may then be safely concluded that either there still exist some intact axis cylinders, or that the nerve is undergoing the process of regeneration. In the latter case it is one of the first of the signs of regeneration to make its appearance.

The special value of the electrical tests is that they afford objective evidence in place of the subjective signs afforded by the other methods of observation. We may suspect, from the appearance of the skin and from the tone of the muscles, that the loss of voluntary power in a limb is only functional; but a very brief examination of the muscles of this limb by the faradic current will definitely prove to us, if the muscles contract, that the case is a functional one; and, if no contraction is elicited, that there is an organic nerve lesion.

There are only two very rare and almost negligible exceptions to the above rule; it may, in rare cases, happen that excitation of the nerve above the lesion excites no contraction, but that excitation of the nerve below the lesion excites a faint contraction. This may occur in very recent cases of injury, where sufficient time has not elapsed for the peripheral fibres to degenerate completely, or it may possibly occur in slight cases of nerve compression, such as Erb's paralysis of the musculo-spiral nerve from slight compression. The errors likely to arise from these rare exceptions can be readily guarded against.

Electro-diagnosis by the faradic current was originally introduced by Duchenne, of Boulogne, in 1849, and, in spite of all the clinical and laboratory research which has been conducted since that time, it still remains the most valuable of all the methods at our disposal. The faradic current demonstrates the condition of the nerve. When using the ordinary faradic coil the current is not of sufficient duration to excite a contraction in the more slowly

acting muscle, if its nerve has been severely injured. As Adrian and others have shown, the mechanism by which a nerve is excited is a quick one, 1/1,500 sec. or less, and the mechanism by which a muscle is excited is a comparatively slow one, 1/100 sec. or longer. An ordinary faradic coil of the clinical type imparts a stimulus with a time duration of about 1/1,000 sec.; this is of long enough duration to excite a contraction when applied through the quick mechanism of the nerve, but it is not of sufficient duration to excite the more sluggish muscle deprived of its nerve. These observations only apply when using faradic coils of the ordinary clinical type; it is possible by using the enormous voltage obtainable from a powerful X-ray coil to excite a contraction in a denervated muscle.

When a muscle fails to react to the ordinary faradic current, we conclude that its nerve is not functioning; it may be completely divided, or it may be compressed by fibrous tissue, scar tissue, or callus, or it may be temporarily injured by external pressure, as in Erb's paralysis, or by being nipped by forceps during an operation.

If no contraction results from stimulation of the nerve or muscle by the faradic current, resort is made to the galvanic current to ascertain the condition of the muscle.

A healthy muscle with intact nerve supply will contract to a galvanic current strength of 1 or 2 ma. A muscle with its nerve supply injured may at first react to a stimulus of 3 or 4 ma.; as time goes on, if its nutrition is not fully maintained by suitable electrical treatment, it will require larger and larger stimuli, 7, 15, or 20 ma., and may finally reach a condition in which the muscle substance, having entirely lost its contractility, becomes fibrosed and will not react to any electrical stimulation.

The terms, partial R.D., complete R.D., introduced by Erb, have for a long time been in common use. Partial R.D., or, to express the term fully, partial reaction of degeneration, includes those cases in which there exist diminished faradic and galvanic excitability of the nerve, diminished faradic excitability of the muscle, and there

may exist either galvanic hypo- or hyper-excitability of the muscle.

The complete reaction of degeneration is distinguished by complete loss of faradic and galvanic excitability of the nerve, complete faradic inexcitability of the muscle, and is usually marked by diminished galvanic excitability of the muscle. In testing the galvanic excitability the motor point is found to be displaced towards the tendon, the so-called longitudinal reaction, or, less correctly, the displacement of the motor point.

By far the most important of the electrical signs of complete R.D. is the alteration in the character of the contraction, the sharp and brisk contraction of the normal muscle giving place to a slow sluggish contraction, in some cases almost vermicular in character.

Apart from the fact that these terms of partial and complete R.D. have for so long been generally accepted, there is little to recommend their retention, for they are very indefinite and inaccurate. If, however, they are adopted, the term absolute R.D. should be added. The term has a very definite and exact meaning; it is applied to those cases in which the function of the nerve has been completely destroyed and the muscle tissue has been so injured, or has so completely degenerated into fibrous tissue, that it has lost all its contractility and is inexcitable by any form of electrical stimulation.

It has been the custom to include the so-called sign of Polar Inversion among the indications of complete R.D. In a muscle with intact nerve supply, a contraction is most readily obtained with the galvanic current at the make or closing of the current with the negative or kathodal electrode, K.C.C.; at the break or opening of the current, a strength eight or nine times as great is required in order to excite a contraction, and in this case the contraction is more readily obtained at the positive pole or anode, A.O.C. These results are expressed in the following formula:

$$K.C.C. > A.C.C. > A.O.C. > K.O.C.$$

It has been demonstrated by the experiments of Cardot

and Laugier (1) on the sciatic nerve and gastrocnemius of the frog, and by the observations of Bourguignon (2) on human nerves and muscles, that at the make of the current it is the negative pole which is alone active, and at the break of the current it is the positive pole only which excites contraction. The so-called A.C.C. is a 'virtual' K.C.C. situated deeply in the tissues or the substance of the muscle, and the so-called K.O.C. is a 'virtual' A.O.C. similarly located.

At first sight it might seem to be possible to ascertain the degree of degeneration which had taken place in a muscle from the number of milliamperes required to excite a contraction. Unfortunately, this simple method will not give accurate information of this kind, owing to the varying factors, such as alterations in the dryness and thickness of the skin, &c., which nullify the value of such a calculation.

The limitations of these methods have induced physiologists to seek for a more accurate and definite technique. As the result of the work of the French physiologist, Lapicque, and the researches of Keith Lucas and others in England, this has been found by ascertaining the quickness of excitability.

To find the chronaxie of a nerve or muscle, the weakest strength of current, without regard to its duration, which will produce the faintest perceptible contraction is first ascertained. This strength of current forms what is termed 'the threshold of excitation' or 'the single rheobase'.

Physiologists, in order to make their results more accurate, double this strength of current, thus obtaining what is termed the 'double rheobase'. No calculations are based on the strength of this current; it is simply given the value of 10, and the further strengths employed are multiples of this number. In this way the errors, due to variation in skin resistance, which prevent accuracy in the ordinary methods, are obviated.

The next step is to ascertain by means of the Keith Lucas pendulum, Lapicque chronaximeter, or other instru-

ment capable of measuring minute fractions of a second, the minimum duration of time which is required to excite a contraction with this strength of the double rheobase. This time, expressed in fractions of a second, forms the chronaxie of Lapicque for the nerve or muscle under examination. It will thus be seen that the chronaxie is concerned with two factors, the strength of the stimulus and its duration.

According to Lapicque, the ionic concentration, which follows the make and break of the current, brings about a disturbance in the colloidal state; it is the resulting modification of the colloidal state that constitutes the essential mechanism of an excitation. The chronaxie depends on a variation of the colloidal state: with a given change in the ionic concentration, this secondary disturbance of the colloidal state occurs more or less rapidly according to the colloidal properties of the tissues affected. (3)

It is evident that a current must have a certain minimal strength or it will not excite a contraction; it must also have a certain minimal duration, below which a current of a given strength will not excite a contraction. If the minimum duration during which a current of a certain strength will produce a contraction is reduced, no contraction will result unless the strength of the current is increased; and, as the duration is decreased, the strength has to be increased in a rapidly increasing ratio.

The chronaxie of Lapicque is only concerned with weak currents. By this method it has been found that an uninjured nerve excites a contraction in its muscle with a current lasting only from about 1/1,500 to 1/2,000 of a second; a denervated muscle will require a stimulus lasting 1/100 of a second, and as degeneration advances in the muscle this period will be increased to perhaps 1/20 or 1/10 of a second. There is therefore a very considerable difference between the chronaxie of the nerve and the muscle; and this difference explains why an ordinary faradic coil, the duration of the stimulus from which is about 1/1,000 of a second, will excite a contraction when the

nerve is uninjured, but will not do so when it is not functioning.

If the strength of the stimulus is enormously increased, as for instance by the use of an X-ray coil or by a spark from a powerful static machine, a contraction can be excited even in a paralysed muscle by a current of very brief duration, 1/1,000 second or less. Such currents are not used in clinical work as their application is too painful. By further reducing the period of the stimulus, a period is at length reached at which no contraction will occur, however strong the stimulus may be.

Adrian published in the *Archives of Radiology and Electrotherapy*, May 1917, a most instructive and original paper entitled 'Physiological Basis of Electrical Tests in Peripheral Nerve Injury'.

'Either by varying the current strength and finding the least effective duration corresponding to each strength, or else by varying the duration and finding the least effective strength', he was able to plot out a series of curves, which yielded most valuable and significant results.

He obtained three types of curves: C, the simple curve with short chronaxie of intact nerve and muscle; A, the simple curve with long chronaxie of denervated muscle; and B, a complex curve, 'made up of a steep, sharply bent curve when the current strength is high and the duration short, and a slower and more gradual curve when the duration is longer and the strength less' (Fig. 23).

The steep, sharply bent curve of brief duration obtained with high current strength occurs only in the process of nerve degeneration or regeneration. When the nerve has fully degenerated, only the slow and gradual curve is found.

The sharply bent curve relates to the chronaxie of the nerve, the gradual curve to the chronaxie of the muscle. There are no intermediate curves. 'We must conclude, therefore, that there is no gradual transition from the rapid to the slow curve as the nerve degenerates. Instead of this we have a period in which both curves are found

together, and the transition consists in one curve becoming more and more prominent to the exclusion of the other.'

Adrian gives in his paper an exceedingly interesting and instructive series of curves, taken at twelve intervals from the third to the sixtieth day, of the reactions of the orbicularis palpebrarum in a case of peripheral facial paralysis (Fig. 24). He thus describes the changes in the curves:

'During the first eight days after the loss of voluntary

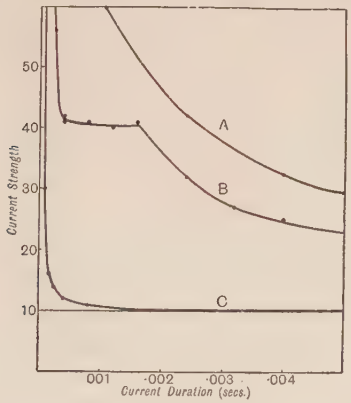


Fig. 23. Diagram to illustrate Adrian's Curves. Reaction of Tibialis Anticus:

A. After complete division of the Sciatic.
B. Recovering from Acute Anterior Poliomyelitis.
C. With intact nerve supply.

power the curve remains absolutely unchanged. On the twelfth day a double curve is obtained, the discontinuity occurring when the strength is 20. On the fifteenth day the rapid curve has been almost entirely replaced by the slow, but it is still possible to detect a break in the curve at a current strength of 50, and with greater strengths than this the curve is of the rapid type. On the sixteenth day no discontinuity can be found, and the curve is of the slow type throughout. The chronaxie of the slow curve becomes gradually longer and longer until the thirty-third day, when the rapid curve reappears at a current strength

of 50. The first suggestion of returning voluntary power had appeared a day or two before, but it was not possible to say for certain that any power had returned until the thirty-fifth day. After the thirty-third day the rapid part of the curve reappears at weaker and weaker current strengths, and eventually it completely replaces the slow curve about sixty days after the onset of the paralysis.'

Unfortunately these methods, so valuable, so instructive, and so accurate, belong to the laboratory rather than to the bedside. Tinel, in his invaluable book, *Blessures des Nerfs,* referring to the simplified method of Lapicque, states: 'One must, nevertheless, confess that, even when simplified, these researches are always very long; many hours are often necessary for the methodical examination of a single patient.'

After all, the value of these observations is physiological rather than clinical, for, as we have seen above, in the admirably worked out record of the course of degeneration and regeneration in the orbicularis palpebrarum, 'the first suggestion of returning voluntary power had returned a day or two before' any change in the electrical reactions, and two days after the first electrical sign voluntary power was definitely present.

Two other methods have been devised for ascertaining the quickness of excitability of nerve and muscle: the method of Bourguignon and Laugier, and the condenser method of Lewis Jones and Cluzet.

### The Method of Bourguignon and Laugier

This procedure is based upon the difference in character between the induced wave at the make and the induced wave at break in an induction coil. The wave at make of the current causes self-induction in the coil, and this establishes a contra electro-motive force, which has the effect of weakening and lengthening the discharge. On the other hand, the wave at break sets up no self-induction and is consequently stronger and shorter in its discharge, provided a condenser is used to quench the spark at break,

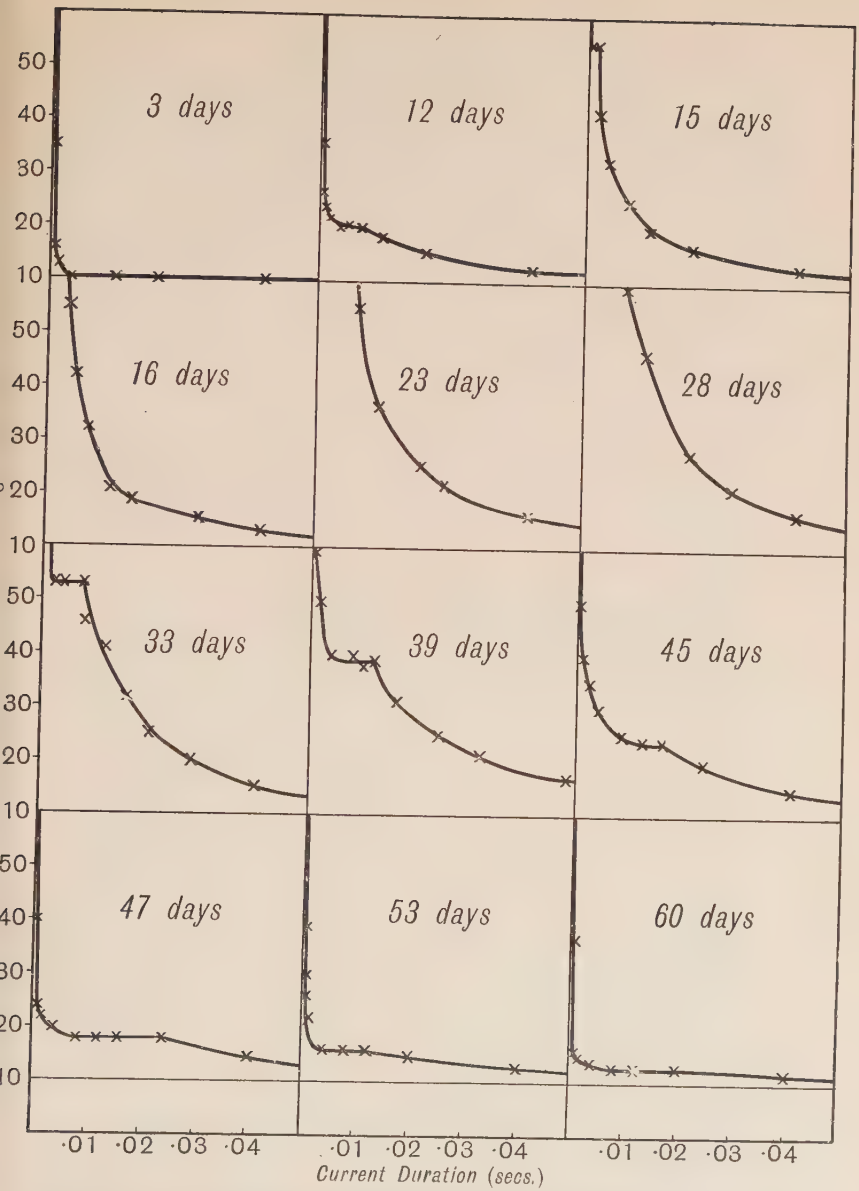


FIG. 24. Adrian's Curves of Facial Paralysis (peripheral). Reactions of Orbicularis Palpebrarum, from onset to recovery.

which would otherwise lengthen the wave. The healthy nerve and muscle, with their quicker chronaxie, are more adversely affected by this lengthening of the wave than the injured nerve and muscle of longer chronaxie. Hence the current at make will require a greater relative increase over the current at break to produce a contraction in a healthy than in an injured nerve and muscle.

By noting the degree of sheathing of the primary required to excite a contraction both at make and break, an index of excitability can be drawn up for any coil, but this index is only of value when it is used with the coil for which it was made.

This method has little practical value, for it involves most elaborate mathematical calculations, and the intensity of the stimuli required to excite a contraction at make causes far too much pain to render the method a popular one with patients.

### The Condenser Method of Cluzet and Lewis Jones

This method, introduced into England by Lewis Jones, and into France by Cluzet shortly before the Great War, seemed for a time likely to come into general use. The simplicity and neatness of the apparatus, and the painless character of the lower capacities, were strongly in its favour.

It was claimed by Lewis Jones (4) that 'when the condenser method of testing has been further developed by clinical use, it will supersede the methods of testing now in vogue, and will enable electrical testing to provide additional information as to the nerve and muscle in disease'. The use of the condenser, however, in England, appears to be already on the down grade, and many of those who were its most enthusiastic supporters are returning to the older methods. It was soon found that muscles in an advanced stage of degeneration, which were inexcitable by condenser discharges of high capacity, were still excitable by a galvanic current of easily tolerated intensity. It was indeed admitted by Cluzet that for test-

ing very degenerated muscles the use of the galvanic current should be retained.

The ability to obtain comparative results from the observations of different workers was supposed to be one of the special advantages of this method, and Cluzet, with this object in view, laid down that the electrodes used should be of a standard size, the indifferent electrode 100 square cm., and the active one 1 square cm. Little attention has been paid to these necessary details, and still less attention has been paid in actual practice to the constant maintenance of the charging current at 100 volts, a most important factor if comparative results are to be obtained. It is very rarely that a condenser set is fitted with a voltmeter. It appears to be assumed that a town supply of nominally 100 volts remains constant at that tension, which is certainly not always the case.

In my experience it requires less time to find out whether the nerve is excitable or not to the faradic current, and to ascertain the character of the muscular response to galvanism, than to find the minimum condenser capacity with which a minimal contraction is obtainable; and the information afforded by the former method is, in my opinion, more complete and precise than that obtained by the latter. By far the greatest objection, however, and the one which is inducing most workers to abandon condenser testing, is the very troublesome tendency of condenser stimuli to spread to the antagonistic muscles. In certain cases of infantile paralysis the relatively painless character of the weaker condenser stimuli renders their employment a convenient method where the paralysis is not complete.

The above review of the various electrical tests shows that the old-established faradic and galvanic methods have not been superseded by any of the more modern procedures. The chronaxie method, in the hands of the physiologists, has been invaluable for demonstrating the physiological principles upon which the clinical reactions are based, but it is needlessly elaborate and far too lengthy a procedure for clinical purposes.

It is clear that the process of degeneration in a nerve is not of the same type as in a muscle. In a nerve the process is a sharply defined and an abrupt one; in a muscle it is a gradually progressive and slow process. In testing a nerve, the point to be determined is whether there exists continuity of axis cylinders to the end plate in the muscle; if this continuity exists, the nerve will react to appropriate stimulation. When this continuity is broken the excitability of the nerve suddenly ceases. In testing a muscle the question to be determined is an entirely different one; here it is not a definite question, 'Does continuity exist or not?' The question in this case is, 'What is the degree of excitability or contractility in the muscle?'

The faradic current will answer the first question by showing whether or not the nerve is excitable by faradic stimulation. The degree of excitability and contractility in the muscle will be demonstrated by the character of its response to galvanic stimulation.

Since the question to be answered is so different in the two cases, it is reasonable to adopt a different method in the two cases, rather than to attempt to show a gradual transition of combined improvement in the nerve and muscle which does not in reality exist.

The return of voluntary power appears to be equally as sudden and abrupt as the return of electrical excitability in the nerve. 'It suddenly came like a shock', one patient remarked to me, who, after many months of complete paralysis of the musculo-spiral nerve,made a complete recovery some weeks after his nerve had been freed by operation. 'The initial change always comes as a surprise to me', an officer, suffering from a regenerating lesion of the brachial plexus, remarked to me when discussing the suddenness of return of voluntary power in the different muscles, as the nerve regenerated downwards.

In everyday practice it will be found that the combined faradic and galvanic methods will fulfil all essential requirements, but there is yet another method, which would appear to have a distinct value in certain cases, by affording

a graphic record of the degenerative and regenerative changes in muscle. This process can also be used for ascertaining the degree of excitability in a nerve, but it is in relation to muscle testing that it appears to me to possess special importance. This is the graphic electro-diagnosis of Larat, fully described in *Traité pratique d'Électricité médicale* by J. Larat, 1910, from which work the following extracts are taken.

Larat claims to have applied to clinical work the methods which previously had only been used in laboratories for experiments on animals. He designed an apparatus consisting of a circular band or bracelet, which was inexpansible except for about 3 cm. of its circumference, where a band of elastic was inserted. In this elastic an expansible rubber bulb was fixed, which communicated by a rubber tube to a tambour or drum. In connexion with this drum a stylet recorded the curves on a clockwork-driven cylinder. The speed of this cylinder was regulated to give a maximum rate of one revolution in twenty minutes. In its application the point was first ascertained, by the ordinary methods of testing, at which the muscle swelled most in contracting, and the bulb was then applied at this point. The stimulation was next repeated, preferably by the bipolar method to obviate current spread as much as possible, and in this way a tracing of the contraction was obtained.

Larat insists on the importance of comparing a tracing from the sound side with one from the affected side. 'The value of the method depends on this comparison.' He claims that the personal factor of the observer is eliminated by this procedure, and that variations in the contraction so minute as to escape the eye of even a trained observer can in this way be delineated. He illustrates his work with a series of curves showing the rapid, almost vertical rise and fall of healthy nerve and muscle, increasing in height and abruptness in hyper-excitability and with an increase in strength of stimulation. He shows the gradual, slight, and prolonged rise and fall of degenerated muscle,

curves illustrative of various diseases, curves indicating the progress of recovery, curves of good prognosis and those of bad omen.

The delicacy and accuracy of this method should render it possible to obtain, from successive changes in the type of muscle curves, valuable information in regard to the prognosis, diagnosis, and treatment of nerve injuries. If the curve of a muscle with an injured nerve steadily improved in its type of contracture under electrical treatment, it would be an indication for the postponement of operative treatment. If the type of curve tended to lengthen and flatten in spite of all treatment, it would indicate the need for early operation. A rapid improvement would point to compression of the nerve rather than to section. Moreover, this method should yield a much-needed criterion of the relative value of various electrical and other physical methods.

Amidst the interest excited by the scientific methods of electrical tests there is a very real danger of losing sight of the special function of electro-diagnosis in peripheral nerve injuries. The main object of electrical testing is to enable the surgeon, from the report of the electrotherapist, to form as clear an opinion as possible of the condition of the nerve and muscle. In order to achieve this object the importance of adopting one universal and standard method of electrical testing cannot be too strongly emphasized. In the present state of our knowledge there can be no doubt that the method for universal adoption should be the combined galvanic and faradic method, which is both the simplest in practice and the one best understood by the surgeon. So far as time permits, there is no reason why the electrotherapist should not amplify, for his own records, the information thus obtained by the graphic or other method; in fact, it is desirable that he should do so; but the report to the surgeon should be as simple as possible. It should merely state in simple and clear language whether faradic reaction is present or not; and, if the faradic reaction is absent, the character of the gal-

vanic reaction should be given. The electrotherapist might also briefly state the conclusions which he draws from these observations in reference to the condition of the nerve and muscle.

The practice which exists in a few hospitals of allowing the nurse or masseuse to take the electrical reactions cannot be too strongly condemned; conclusions based on such work are entirely valueless. To find the faradic reaction in a normal case is certainly an easy procedure, but it is often a most difficult matter to be certain of the absence of faradic reaction and to form a correct conclusion in regard to the condition of a muscle from the type of its contraction.

Only those with most experience fully realize how easy it is to make mistakes. As Zimmern and Perol remark (*Electrodiagnostic de guerre*): 'C'est le médecin qui fait l'électrodiagnostic qui lui donne sa valeur.'

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1. Cardot and Laugier, *Journal de Physiologie et de Pathologie générale*, 1912.
2. Bourguignon, *Revue Neurologique*, 30 April 1914.
3. Lapicque, 'La Théorie de l'Excitation Électrique', *Compt. Rend. de la Société de Biologie*, March 1927.
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## CHAPTER II

## THE ELECTRO-DIAGNOSIS OF NERVOUS AND OTHER DISEASES

APART from the electro-diagnosis of peripheral nerve lesions, information of value in the diagnosis of certain diseases of the nervous system may be obtained by electrical means. The following variations from the normal electrical excitability of nerves or muscles may occur. There may be faradic hyper-excitability or hypo-excitability, galvanic hyper-excitability or hypo-excitability. Or there may be excitability to any form of electrical stimulation.

As a general rule, where the tendon reflexes are increased, both galvanic and faradic hyper-excitability will be found.

Hyper-excitability to the faradic current will be found in cases of hemiplegia of recent occurrence, and in cases of tetanus and chorea.

Hyper-excitability to the galvanic current will exist in the early stages of hemiplegia, in tetanus, chorea, and in the initial stages of diseases of the spinal cord.

Hypo-excitability to the galvanic and faradic stimuli will be found in advanced cases of tabes and hemiplegia, in paralysis agitans, and in the later stages of many diseases of the spinal cord.

Complete electrical inexcitability occurs in severe and advanced cases of anterior poliomyelitis, in the Aran-Duchenne type of progressive muscular atrophy in syringomylia, &c.

Different forms of special reactions are named after their various discoverers. In relation to the faradic current, there is the myasthenic reaction of Jolly, and also the myotonic reaction of Thomsen.

In relation to the galvanic current, we have the reactions of Erb, Remak, and of Rich.

The two first named are the only ones we need consider. The myasthenic reaction of Jolly occurs in the disease

myasthenia gravis, a disease which is characterized by the fatigue which supervenes when voluntary movement takes place in the muscles supplied by the motor nerves of the muscles of the eye, the facial, the hypo-glossal, the glosso-pharyngeal, and the pneumogastric nerves. The contraction resulting from voluntary effort rapidly becomes weaker and weaker, gradually fades away, and no further contraction can be excited by voluntary effort until after a period of rest.

Corresponding phenomena are exhibited on faradic stimulation. The muscle contracts, then, in a few seconds, the contraction gradually fades away, although the stimulus is continued, and no further contraction can be excited until after a period of rest. The single shocks of the galvanic current, as interrupted by a metronome, are not sufficiently rapid to excite this phenomenon of fatigue, but it would doubtless be obtained from the use of the Leduc or Frimandeau currents. The reaction of Jolly has been experimentally produced by Marinesco in a healthy patient, by compressing the tested limb by an Esmarch bandage for half an hour previous to the experiment. In a modified form also this reaction is occasionally found in cases of Grave's disease, in some hysterical paralyses, &c., but not with the same distinctness nor to the same marked extent as it occurs in myasthenia gravis.

The myotonic reaction of Thomsen occurs in myotonia, or Thomsen's disease. This disease is characterized by tonic cramp of the muscles on attempting voluntary movement. 'The contraction which the patient wills is slowly accomplished; the relaxation which the patient wills is also slow' (Osler). This phenomenon is repeated in the contraction provoked by the faradic current. The muscle responds to a current of normal strength, but the response is very slow, and is continued beyond the application of the stimulus, then slowly relaxes to quiescence. If a coil is employed, fitted with a trembler, the rate of interruption of which is adjustable, as in the Tripier coil, a rate of interruption, which is too slow to excite tetanus

in normal muscles, will be found to excite a tetanic contraction in the muscles of a patient suffering from this disease. For though the stimuli are infrequent, they will, nevertheless, be sufficiently rapid to maintain the contraction in these slowly relaxing muscles.

It will be seen that in these reactions we reproduce by electrical means the distinguishing features of the diseases in which they are applied.

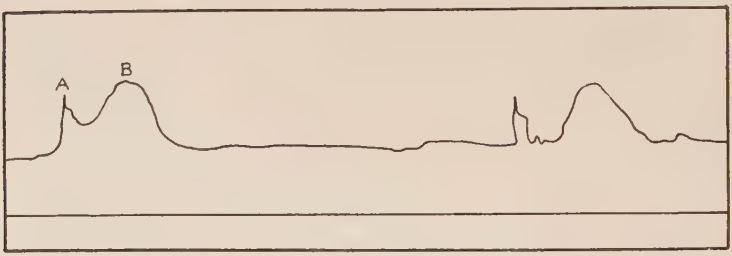


FIG. 25. Myograph of myotonic contraction showing A the primary and B the secondary contraction. (After Pansini.)

This myotonic reaction to faradism has been termed the 'farado-tonic reaction'. There is also in myotonia a change in the reaction to galvanism; the resulting contraction in this case is tonic and is prolonged for a certain time after the cessation of the stimulus, 'the maintained galvano-tonic contraction' ('contraction galvano-tonique durable'). By means of myographic tracings Pansini (1) has shown that this maintained galvano-tonic contraction is made up of two secondary contractions, the first rapid, the second sluggish (Figs. 25, 26). Pansini's myographs show the first of these contractions with a rapid rise, a sharp peak, and a rapid decline; the second contraction is shown with a slow rise, a well-rounded peak, and a slow decline. The first contraction, then, is of the type of a normal muscle reaction; the second contraction is an abnormal one, slow in its rise, maintained for a time near its maximum, and slow in its decline. It is argued by Pansini and Babonneix that these two curves are due to

the contraction of different substances, the first being due to the contraction of muscle fibres, the second to the excitation of sarcoplasm. In Fig. 25 the sharp rise of the primary contraction A suggests the stimulation of the nerve; the gradual curve of the secondary contraction B suggests the occurrence of the direct stimulation of the muscle after the excitation of the nerve has ceased.

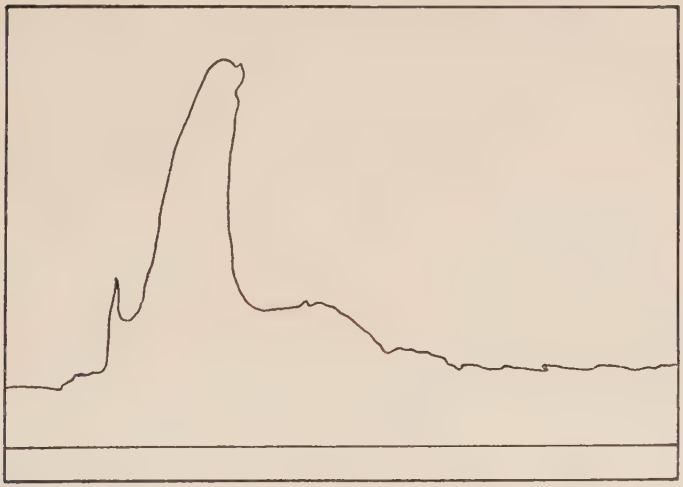

FIG. 26. Myograph showing a variety of the myotonic contraction, with the secondary contraction higher than the primary. (After Pansini.)

The maintained galvano-tonic contraction (the total myotonic contraction of Huet and Bourguignon) is found also in the muscular dystrophies; but, in Thomsen's disease, the reaction is generalized throughout the muscles, and in the case of the dystrophies it is confined to a few muscles.

A non-maintained form of myotonic reaction (the partial myotonic reaction of Huet and Bourguignon) occurs in cases exhibiting the reaction of degeneration, and in the early stages of the muscular dystrophies.

Babonneix, to whose exhaustive and instructive paper,

'Le Syndrome électrique de la réaction myotonique', (2) I am much indebted for information on this subject, attributes the myotonic reaction in Thomsen's disease to the incomplete development of the sarcoplasm, which thereby retains indefinitely its embryonic character and is not converted into muscular fibres. He considers that the explanation of the myotonic reaction occurring in muscular dystrophies is not so clear, but thinks that the reaction in this case may be due to a destruction of the muscular fibres, or to an increase of the sarcoplasm cells.

Other forms of electro-diagnosis, which do not appear to have been studied in this country, are practised by the French electrotherapists.

Electro-diagnosis, based on voltaic vertigo, is employed in certain diseases.

The diagnosis is based on the following points: on whether the patient hears noises or bruits on the passage of a current through his ears, the moment at which he hears them, and in which ear. Attention is also paid to whether vertigo is produced; if so, to which side the patient falls, or feels himself falling.

The technique of these tests appears to be troublesome, the information obtained thereby is very limited, and does not appear to be conclusive.

Electro-diagnosis in gynaecology depends on the relief or excitation of pain which follows the passage of faradic or galvanic current in the neighbourhood of the ovaries and uterus.

In the case of ovarian pains, if the passage of a faradic current removes or relieves the pain, its nature is assumed to be hysterical, and surgical intervention is contra-indicated. If the pain is thereby unrelieved or increased, then the lesion is, except in rare cases, due to organic disease of the ovaries, and surgical intervention is called for.

The galvanic current is applied by means of an intra-uterine electrode. The following are the conclusions which Apostoli deduced from this method.

1. Every uterus which readily tolerates a current of

100 to 150 ma. (a very large current!) is a tolerant and healthy uterus, the appendages of which are also healthy.

2. Every uterus which does not readily tolerate 50 ma., and which shows signs of inflammation after its application, is a uterus of which the appendages are open to suspicion.

3. If the uterus is intolerant of a current of 20 or 30 ma., or reacts after such an application, its periphery is seriously affected.

4. If 20 ma. are not tolerated, the annexes are too seriously affected to admit of their preservation.

5. If the intolerance to the current diminishes, operative treatment should be postponed, as it is either a case of hysteria or a case on the road to recovery.

Of course before making such examinations the possibility of pregnancy must be definitely eliminated.

The chief practical point which is made clear by these observations is the one which is pointed out later when dealing with the intra-uterine galvanism in the treatment of endometritis, namely, that if a current of 30 ma. causes much pain, the electrical treatment should be discontinued, and the case handed over to a surgeon or gynaecologist.

The method of electro-diagnosis which is based on variations in the electrical resistance of the human body is an extremely difficult and complicated one; moreover, the results obtained are neither free from doubt, nor of much value.

Valuable information can be obtained from the application of the faradic current to cases of divided or ruptured muscles or tendons. By exciting a contraction by this means, it can be readily ascertained whether the tendon or muscle has been completely divided or ruptured, and also which muscles or tendons are so affected by an injury.

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# PART VI

# AN OUTLINE OF THE APPLICATION AND OF THE MODE OF ACTION OF ELECTRICITY IN CERTAIN DISEASED CONDITIONS.

## CHAPTER I

## DISEASES AND INJURIES OF THE MUSCLES, LIGAMENTS, AND JOINTS.

MUSCULAR wasting due to injury or disuse can, when the nerve supply is unaffected, be readily and quickly cured by electrical stimulation. That form of electrical stimulation should be selected which most painlessly and efficiently excites a contraction most closely resembling the physiological type. Such a contraction is of a tetanic character, and in most instances is most efficiently and most simply excited by the use of the faradic coil. The stimulus should be applied with even gradation from zero to maximum strength, and should alternate with periods of intermission to enable the muscle to rest between each stimulation. It should be maintained at its maximum strength for a short but definite period.

The development of this method of graduated muscular contraction is due to Dr. Morton Smart, whose attention, whilst a student at Edinburgh, was drawn by Professor Annandale to the great wasting of the quadriceps extensor that followed the operation for removal of the semi-lunar cartilage from the knee joint. As the outcome of experimental work with several types of coils, an apparatus was ultimately evolved by means of which the operator was enabled to control the muscular contraction elicited and to adjust it to the type of case under treatment.

The method of graduated muscular contraction is accomplished by gradually sheathing the core of this specially designed faradic coil with the operator's right hand—the

strength of the current is thus gradually increased—whilst the operator's left hand applies the small active electrode to the muscle under treatment. At the same time, the left hand grips the treated muscle; in this way the operator appreciates the degree of the resulting contraction and can simultaneously sheathe with his right hand the core of the apparatus so as to produce the degree of contraction required. The core is allowed to remain at the maximum point of sheathing for a definite pause, and is then slowly and steadily withdrawn. This procedure is repeated twenty times or more a minute. The chief advantage of this method is that the type of contraction is at all times under the direct observation of the operator and can so be regulated as to obtain the maximum efficiency of contraction, and, above all, the operator is enabled to appreciate at once from the weakening or flickering of the contraction if the muscle becomes over-fatigued.

The condition of muscle tone is of such great importance to the electrotherapist in his work that he should make himself acquainted with its physiological as well as with its practical aspect.

Physiologists have shown that, if four or five stimuli a second are applied to the uncut nerve of a muscle, a tracing of a steady, continuous contraction curve is obtained: if similar stimuli are applied to the cut peripheral end of a nerve, a series of distinct twitches are registered in place of the continuous curve; from these experiments the existence of a tonic reflex is deduced.

In Part II, Chapter III we have quoted the experiments of Adrian which show that traction on a cat's foot sets up interrupted currents, varying in frequency with the degree of the applied stimuli, in the sciatic nerve. It has been inferred that the normal tone of a muscle is maintained by such currents originating from the traction or tension which a muscle in good tone exercises on its tendon.

When a muscle has lost its tone as the result of injury to the joint with which its action is associated, or from the rupture of some of its fibres, or as the after-effect of neuri-

tis, the recovery of its normal tone is a very slow process, owing to the lack of the currents that maintain its tone when in a healthy and normal condition. The graduated muscular contractions, excited by the faradic coil, set up a traction on the muscle tendon and so restore the currents essential for the maintenance of normal muscle tone.

The muscles have been well described as the first line of defence against injury of the joints. That is to say that the muscles when in a normal state of tone will respond so quickly to a sudden call upon them that the effect of a sudden slip or strain will be taken up by them before it has time to fall upon and rupture the ligaments of a joint. For example, if a person, whose leg muscles are in a state of good tone, slips off the kerb, the muscles of the leg will respond promptly and will take up the strain of the slip before it has time to fall on the ligaments and perhaps rupture them. The tone of a muscle in this respect may be likened to the supports (the stays, shrouds and runners) of the mast of a sailing ship; if these stays are not set up taut, on a squall of wind occurring, the mast may be broken before the slack stays can take up the strain. If, however, these supports are properly rigged, the strain is taken by them before it falls on the mast.

The treatment of injuries occasioned by the lack of muscle tone is frequently called for in the practice of electrotherapy: a middle-aged person, for instance, after a prolonged period of inactivity due to a sedentary occupation may, without any previous preparation, undertake a long day's shooting. He then finds that his knee joints, which have caused him pain whilst walking over rough ground, swell up at night. On examination, the extensor muscles of the thighs are found to be flabby; when their normal tone has been restored by a few treatments of graduated muscular contractions, the former difficulty in walking completely disappears. Many instances of a similar kind could be quoted: the following example is a typical one. An elderly lady, who had sprained her ankle six months previously, and had undergone a prolonged

period of rest and splintage, was sent to me for treatment for 'rheumatism' of the injured ankle. When she came for treatment there was no evidence of any rheumatism, the ankle could be passively moved in all directions without exciting any pain, but the gastrocnemius was totally devoid of tone and as flabby as a jelly-fish: when she attempted to stand on the affected foot she had great pain, and she was unable to walk without the aid of two sticks. It was obvious that her disability was due to lack of tone in the muscles of her leg, and that her weight, when standing, was thrown on the ligaments of the ankle joint. After a course of faradic stimulation to the muscles of her leg, she was able to walk three miles without pain, and she was able to complete her cure by walking a progressively increasing distance.

Much of the pain that occurs on standing in cases of sciatica, after the acute symptoms have subsided, is due to the lack of tone that persists in the muscles of the leg; this condition can be quickly cured by a short course of electrically provoked exercises.

It is said by many football experts that slipped cartilage and other knee injuries are of far more frequent occurrence nowadays, when football players ride so much in motor-cars and 'buses, instead of as formerly taking walking exercise; such an increased liability to accident may be attributable to a diminished muscle tone due to lack of exercise. When treated by this method of graduated muscular contraction, it is surprising how quickly a wasted and flabby muscle regains its bulk and tone. Perhaps this result is best seen in the treatment of the wasted muscles of the knee joint by the three-point method of stimulation in a case of displacement of the internal semilunar cartilage. Improvement in the tone of the three muscles treated, the vastus internus, the quadriceps extensor, and the tensor fasciae femoris, is clearly apparent after a few treatments. The electrical development of these muscles in such cases affords an instance of the help which the electrotherapist is able to render the operating

surgeon before and after the excision of the semilunar cartilage, the period of convalescence and the recovery of full mobility and strength in the affected joint being very favourably affected by the pre- and post-operative stimulation of the muscles round the joint.

Associated with massage, electrical stimulation by the simple faradic coil, suitably administered, is of the greatest service in maintaining the nutrition of the muscles of the limbs and abdomen in many prolonged and exhausting illnesses. Go round the wards of any hospital you will, turn back the bedclothes and examine the legs of the patients who have been in the hospital for weeks; you will find the muscles of these limbs wasted, flabby, deficient in tone, and the skin harsh, dry, and scaly. By the easily learnt administration of the faradic battery, by rubbing of so simple and elementary a form as hardly to be worthy the name of massage, such conditions could readily be prevented and the patients' period of convalescence materially reduced. But the nurses' energies are directed rather to polishing the pots and pans in the ward than to maintaining the nutrition of the muscles of the patients.

Again, how little attention is paid to the massage and electrical stimulation of the abdominal muscles of the multiparous woman after childbirth; and yet, by the simplest methods, adopted for a short time each day, how much after-trouble in the form of uterine prolapse and intestinal stasis might be readily prevented. But perhaps such observations as these belong to the science of common sense rather than to that of medicine or surgery.

In the treatment of sprains and strains of muscles the value of electricity is quickly demonstrated. A severely sprained ankle, much swollen and bruised, and very painful, can often, provided that no bone has been fractured and no important ligament has been lacerated, be apparently restored by suitable electrical treatment to its normal condition with full restoration of mobility and function and complete removal of pain in less than a week. The best way of producing such results is by means

of the Morton wave current of the static machine. The method by which the cure is produced in such cases is perfectly clear. As the result of the injury, effusion takes place into the surrounding tissues of what John Hunter well termed 'coagulable lymph', and this fluid as it coagulates binds the ligaments and muscles to themselves and the surrounding tissue; so that the least movement causes acute pain from the dragging on and the tearing of the adhesions so formed. The powerful muscular contractions elicited by the electrical stimuli enable the muscles to free themselves from the intra- and peri-muscular adhesions so formed, and, at the same time, by the auto-muscular massage resulting from such contractions, lead to the dispersion of the effused lymph. A preliminary application of diathermy appears appreciably to aid the treatment, probably by inducing a relaxation of the parts and a dilatation of the efferent channels.

It will be evident that, in order to obtain the best and most speedy results, treatment should be commenced as soon as possible after the receipt of the injury; later, as the effusion becomes less and less fluid, the adhesions will become more and more firm as the effused lymph is more and more organized, until they finally become fibrous, and incurable ankylosis results. It is a sound rule to radiograph every sprain and strain in the neighbourhood of a bone or joint before the commencement of treatment: otherwise a time is bound to come when a fractured bone will be overlooked. On one occasion, I was consulted by a patient with a view to the electrical treatment of what he described as a slight strain of the ankle, occasioned by a slight twist of his foot whilst playing lawn tennis. An examination of the injured part showed no sign of fracture, but a precautionary radiograph revealed a fracture of the fifth metatarsal bone. In the same week I was consulted by a cricketer, qualifying for an important match, for what he termed a slight sprain of his thumb occasioned by stopping a hard drive off his own bowling. A radiograph in this case showed a small piece of bone chipped

off the metacarpal bone of the thumb, and therefore I was enabled to predict the occurrence of a certain amount of thickening, which otherwise might have been attributed to inefficient treatment.

Similar cases are of such constant occurrence in electrotherapeutic practice as to render a preliminary radiograph the first step to suitable treatment.

There is one other caution to be pointed out in the treatment of severe strains and sprains; although all swelling and all pain may have disappeared from the injured part at the end, or even before the end, of a week, the parts have not, nevertheless, regained their normal strength in that short period, and if too vigorous exercise, such as Rugby football, is too soon indulged in, a recurrence of the sprain may occur. The electrotherapist should point out this danger to the patient, and in such cases should advise three weeks' or more avoidance of violent exercise; but, in the case of University athletes qualifying for a 'blue', he may rest assured that the risk, and not his advice, will be taken.

Traumatic synovitis of the knee joint is in some respects a similar condition. In recent cases the fluid can readily be removed from the joint by the Morton wave current. A rubber bandage is tightly applied round the knee so as to force the fluid as much as possible into the suprapatellar pouch, a small electrode is fastened over the vastus internus, and the Morton wave current is applied for twenty minutes. The powerful contractions, alternating with relaxation, excited in the quadriceps extensor group, exert such recurrent pressure on the synovial fluid, that after twenty minutes of this treatment it is usually very much reduced in amount and often completely absorbed. In a recent case with an acutely inflamed synovial membrane the fluid will generally reaccumulate by the next day; it can be redispersed by a similar treatment, and at the end of the week, in the majority of cases, there will be no excess of fluid in the joint. In order to obtain these results it is essential that the contents of the joint should

be fluid, and that the quadriceps extensor should be well developed. In most of the old-standing cases from the front during the war I found that this treatment had little effect, and I attributed its failure in such cases to the contents of the joint being semi-gelatinous. Some old-standing cases of hydrops articuli do remarkably well with this treatment; the following was one of the first cases of the kind that I treated.

The patient was a young undergraduate, who came to me in January 1914 for hydrops articuli in both knee joints. He had spent the previous summer in a London hospital without receiving any benefit. During the October term he was unable to get about except in a bath-chair. When he came to consult me he was unable to stand without his splints and without the aid of sticks. The muscles of the thighs were very extensively wasted, the knees appearing as fusiform swellings. The joints had been aspirated, and the contents were found to be sterile. His treatment was divided into two stages: the first part on the Bergonié chair for the redevelopment of the wasted muscles by electrically provoked exercises; the second part, the excitation of the redeveloped muscles by the Morton wave current. At the end of sixteen treatments he was able to walk without the aid of a stick, to bicycle up hill, and for several miles on the level, and there was no excess of fluid in the joints. There was no relapse, except a slight one after an attack of measles during the Easter vacation. During the summer term I showed the case at a meeting of the Oxford Medical Society; he had been playing cricket in the afternoon, but no excess of fluid could be detected in the knee joints. At the outbreak of war he was passed as medically fit, and, I regret to add, subsequently met his death in Gallipoli.

Many old-standing cases of 'water on the knee' appear to be due to weakness or lack of tone in the muscles of the quadriceps extensor group; the intra-synovial pressure is in such cases lowered and the fluid consequently accumulates and persists. The clear indication for treatment

in such cases is the redevelopment of the weakened muscles, thus restoring the normal pressure within the joint and causing a disappearance of the excess of fluid. Electrical stimulation fulfils this indication far more effectually than any other method.

### Tennis Elbow and Rider's Strain

Lacerations of tendons at the point of their origin or insertion, such as occur in tennis elbow or rider's strain, yield more rapidly to electrical treatment than to any other remedy.

Tennis elbow is usually caused by the sudden arrest of a heavy-headed racket at the completion of an overhead service. The strain of arresting the momentum of the racket falls upon the extensor tendons of the hand, wrist, and forearm at their common origin from the external condyle of the humerus.

Inflammation, effusion, pressure, pain, and limitation of movement result from the injury, and are often associated with a localized periostitis.

During the coal shortage occurring during the war and the coal strike I saw several cases of a similar nature in elderly men occasioned by chopping wood with a heavy hatchet or axe.

Tennis elbow should not be regarded as a single definite lesion true to type in all cases, but rather as a variety of lesions in the immediate neighbourhood of the external condyle of the humerus. In some cases there appears to be a slight displacement of the orbicular ligament of the head of the radius: and, if such a condition is the cause of the trouble, the displacement may be reduced by manipulation, and then a speedy cure will follow. In other cases the acute burning pain experienced at night points to a lesion of the periosteum at the point of attachment of the common extensor tendon to the external condyle of the humerus. Diathermy is the method of choice in the treatment of this variety. When examining cases of tennis elbow, it should be remembered that there normally exists a spot

very tender to pressure about half an inch anterior to and slightly below the external condyle.

The effect of the electrical treatment of this condition is to relieve the pain by the decompressor action of diathermy, and to diffuse the effusion by means of static sparks localized on the affected area. The small area usually affected renders the greater density of the static sparks more efficient than the Morton wave current.

In rider's strain the adductor brevis, magnus or longus may undergo a laceration at its point of origin from the rami of the pubes or ischium, or a few fibres may be torn in one or more of these muscles. The most common cause of this injury is the sudden gripping of the saddle when hunting either whilst negotiating a jump or at an unexpected plunge of a restive horse. It is said to be more likely to occur when riding a horse with a broad back or when riding with long stirrup-leathers. A similar strain can also be occasioned by a variety of other causes, such as a straddling slip at football: one case of this kind that came under my care occurred in the bow oar of the University Eight when he was endeavouring to stop the rolling of the boat in rough water.

For the treatment of rider's strain I have abandoned all other methods for that of Morton Smart's technique of graduated muscular contraction, except that in the early stages of the trouble I give one or two preliminary applications of diathermy to the injured muscles.

It is surprising how quickly and completely this condition yields to the graduated contractions when they are properly applied.

The medical profession has been very slow to realize the efficiency of this treatment, with the result that cases of this nature, so common among hunting men, have until the past few years fallen into the hands of the bone-setters, who have been able by the application of electrical methods to produce far better results than medical men have obtained by the old methods of rest, strapping, and supporting bandages.

When treating the injured adductor muscles by faradic stimulation it is easy to judge of the progress of the case by the type of contraction elicited. When the current is first applied to a recently strained muscle, the resulting contraction takes the form of an irregular, flickering, painful contraction; when recovery has taken place, the muscle swells up to the stimulus in an even, tense, fusiform, and painless contraction. When such a contraction is obtained, and not before, the patient is able to resume hunting without fear of a recurrence of his trouble.

### Chronic Rheumatism

In the causation of that wide and divergent group of disorders classified under the name of chronic rheumatism (the inflammation of fibrous tissue) or the equivalent term 'fibrositis', there are two main factors: one is the exciting poison, the other is the lowered resisting power, local or general, of the patient.

The exciting poison varies to a very great extent in its virulence. It may arise from an infective source so virulent as to render any form of electrical treatment of no avail until the infective source, whether the teeth, tonsils, intestinal flora, or whatever it may be, has been effectively dealt with. On the other hand, the exciting poison may be of so mild a type as to be ineffective unless the resisting power of the patient has been lowered greatly. In this latter type the most valuable remedy is electrical treatment, which should be directed to raising the resisting power of the affected area and the general health of the patient.

The treatment of the infective agent does not fall within the province of the electrotherapist: but, nevertheless, as the outcome of his daily experience in dealing with a large number of rheumatic cases of varying types, he necessarily observes the results of the various procedures of dealing with the source of the infection. In this connexion I would like to emphasize very strongly the importance of dealing with the infection from the lower bowel. In my experience

no general treatment has yielded such good results as efficiently administered Plombière douches. It is essential, however, that they should be administered by a specially trained and conscientious nurse. A mere washing-out of the rectum in a perfunctory manner is of no value: but a washing-out of the large intestine in a careful and thorough manner will often yield surprisingly good results. The nurse should be observant and trustworthy, and then her reports on the character of the wash-out will afford the necessary data for a continuance or cessation of the treatment: for herein lies one of the advantages of this form of treatment that it is diagnostic as well as curative, and if the evacuated fluid is clear and free from mucus there is no need to repeat the injections. The Plombière douche is not as a rule adopted early enough; if it were adopted more often in the early stages of treatment, many patients would retain useful and ornamental teeth, harmless tonsils, and unoffending turbinate bones.

In the majority of cases of chronic rheumatism it is the lowered general or local resisting power that is by far the most important factor in the development of the disease. Evidence in support of this contention is afforded by the age incidence of the trouble, and its relation to traumatism, and to climatic conditions and changes.

The so-called rheumatic diathesis is nothing more than a general or constitutional lowered power of resistance on the part of the individual. It will be noticed that on certain days, when there has been a sudden change in the weather from hot to cold, or from dry to damp, or vice versa, that a large proportion of the patients who will attend for their treatments are in very low spirits about the progress that they are making. It is, indeed, the sudden change in the type of weather that appears to affect rheumatic patients more adversely than continued extremes of hot, cold, or damp weather conditions.

This phenomenon would appear to be due in a large measure to the failure of the recently formed fibrous tissue with its deficient blood supply to react reflexly by means

of the heat regulating centre, and perhaps other reflexes, to external stimuli. The increased vascularity and the other reparative changes that result from a prolonged course of electrotherapy afford an explanation of the good results which are obtained in such conditions by suitably administered diathermy or intensive galvanism. In the treatment of chronic rheumatism electrical measures are not merely curative, but they are also to a large extent reparative in character. This is seen in the replacement of the glossy and hairless condition of the skin by a normal appearance and a restoration of the growth of hair over the area treated, by a resolution of fibrous tissue with the disappearance of swelling, and by a restoration of the normal skin temperature.

The results obtained in the electrical treatment of rheumatism and rheumatoid arthritis will largely depend upon the duration of the trouble and upon its situation.

Some of the best results yielded by electrotherapy are obtained from the treatment of chronic rheumatism and early rheumatoid arthritis of the knee joint; the results obtained from the treatment of a similar condition of the hip joint are by no means so readily obtained. The reason for this is very obvious; in the case of the knee joint we are able to arrange two pads of large size, one on either side of the joint, with the result that the lines of force of the current are concentrated, with but little diffusion, upon the diseased part. In the case of the hip joint the lesion is more deeply situated, with the result that the current is widely diffused and cannot be concentrated on the affected area. If any satisfactory results are to be obtained from the treatment of rheumatic conditions of the hip joint, they will only be obtained from treatments of long duration, and high current intensity, continued over a period of some months.

In an early case of rheumatoid arthritis of the knee joint, my experience is that usually twelve treatments, of 60 to 80 ma. continuous current, administered for forty minutes through two laterally placed pads of about 7 inches

by 5 inches, will result in a disappearance of the pain, a diminution of the peri-articular thickening, and a restoration of mobility and movement. If pain is a prominent symptom, a preliminary treatment with diathermy should be administered, the current intensity should be low, not exceeding one ampere, with the size of pad given above, and should be continued for twenty to thirty minutes. My most recent technique is to precede the galvanism by a current of diathermy of one ampere for five or ten minutes.

A relapse may usually be prevented by the application of another course of from six to twelve treatments at the end of six months.

If the disease is of old standing, with much thickening of the joint, more than twelve treatments will be required; and in really advanced cases the treatment should be continued for at least six months. When the pain is not acute each treatment should be followed by massage and movements of the joint: under no conditions can massage be performed more advantageously than after a prolonged treatment of intensive galvanism.

During the course of the electrical treatment there is no reason why any other form of treatment, whether by drugs or sera, should be discontinued. The electrical treatment is solely a local one, and in no way takes the place of constitutional measures. The only precaution to take is to avoid any application to the skin of the joint which might interfere with the administration of the full strength of current.

The following is an example of an exceptionally good result from prolonged treatment of rheumatoid arthritis of both knee joints.

A lady, about fifty years of age, had suffered from very painful and swollen knee joints for several months; the condition had failed to respond to the usual remedies, and the state of the knee joints was becoming steadily worse. The patient was unable to walk, or go upstairs, or even to stand on account of the pain: her bed was consequently made up in the drawing-room on the ground floor, and she

was wheeled from room to room in a chair. She attended in a bath chair for electrical treatment from September 1918 to June 1919; galvanism, diathermy, and massage were administered for an hour on each visit: 110 treatments were given. At the end of this course there was no swelling beyond that due to bony thickening, all pain had completely disappeared: but both knee joints were very stiff and could only be moved through a very limited range by the ordinary manipulative exercises.

I advised her to see an orthopaedic surgeon with a view to the forcible movement of the joints. The arrangement with the surgeon fell through owing to his temporary absence from home. On her own initiative the patient made arrangements with a bone-setter in Surrey. She subsequently gave me a most graphic description of her treatment. The bone-setter was a powerful Irishman, who, in order to obtain the necessary strength for the wrenching of her knees, had to take daily an enormous breakfast of beef steak and several eggs. No anaesthetic was administered, the bone-setter sweated with his exertions, and the patient perspired profusely and nearly collapsed with the pain.

Notwithstanding this violent treatment, there was no recurrence of any pain or swelling of the joints, and the result was completely successful. On her return to Oxford, the patient walked to my house, could bend her knees freely and completely, and to demonstrate her full recovery danced a jig in my consulting room.

Nearly nine years have now elapsed since the completion of the treatment: there has been no relapse and the patient can walk freely. In such cases as this, needing a long period of treatment, it is essential that the patient should have the determination to get well.

### Osteo-arthritis of the Hip Joint

For some years I failed to get any improvement from the electrical treatment of osteo-arthritis of the hip joint; I am convinced that my failure was due to attempting to

benefit these cases by too short a course of treatment. There are few cases more chronic in nature and more atrophic in character than those of osteo-arthritis of the hip joint, and it may be laid down as a general rule that, though acute conditions may be expected to yield to a short course of treatment, chronic cases will require a much more prolonged course, and the more chronic the condition the more protracted must the treatment be.

In 1922 a case of advanced osteo-arthritis of the hip joint was sent to me for treatment with the request that I would give the patient diathermy through the hips for at least six months. The note accompanying the patient pointed out that the radiograph showed extensive absorption of the surgical neck of the femur, and a warning was consequently given against too forcible manipulation of the joint. The patient was very lame and walking occasioned him considerable pain. He commenced treatment on July 17, 1922, and was treated twice a week for the first four months, once a week from October 22 till September 17, 1923; once a fortnight from October 1, 1923 till April 1925, except during April 1923 and August 1924. The improvement was so marked that on September 1, 1922, he was able to walk partridge-shooting from 9 a.m. till 7 p.m., and he continued to shoot during the ensuing winter and to fish during the spring and summer. The later treatments were given at the urgent request of the patient, as he found such benefit resulted in his walking from them that he was unwilling to discontinue electrical treatment. In all he received ninety-eight treatments, and he has suffered no relapse since their discontinuance.

My technique in the treatment of osteo-arthritis of the hip joint is as follows:

Two electrodes, $9\frac{1}{2}$ inches by 6 inches, with the upper corners cut away to avoid the anterior superior iliac spine, are placed one on each hip joint with an underlying pad of four layers of Turkish towelling soaked in salt solution, and are secured in place by a wide rubber bandage.

A diathermy current of 2 amperes is administered for

40 minutes and is followed by the administration for 10 minutes of the Watteville current surged by the instrument described in Fig. 9. The treatment is concluded by 10 minutes of massage, passive manipulation, and exercises. The aim of this method is to diminish pain, to improve the circulation and nutrition of the tissues round the joint, to redevelop the tone of the muscles, and to increase the mobility of the joint.

At the outset of the course, it should be explained to the patient that treatment should be continued for at least six months, and that a short course will fail to secure satisfactory results. During the first three weeks, treatments should be given 3 times a week, then 2 treatments a week for 3 weeks, and afterwards once a week. Unless patients are prepared to undergo a course of such a duration, I decline to undertake their treatment. If such a technique is adopted, it will invariably be found that the results will fully justify the expense and trouble incurred.

In rheumatic arthritis of the shoulder joint a similarly protracted course of treatment will usually result in complete freedom from pain and full restoration of function, if there is no serious bony involvement. No forcible wrenching of the shoulder joint should be attempted, as such a practice is often followed by the development of fresh arthritis and adhesions. The passive movements adopted should occasion no pain, and the patient should be instructed in suitable home exercises.

Before entering upon these extended courses, whatever joint may be involved, radiographs should be taken to guide the treatment and to afford a basis for prognosis.

In advanced cases of rheumatoid or osteo-arthritis, when it is impossible for the patient to afford the expense of a prolonged course of treatment, I advise the patient to purchase a 20-cell dry battery, and to attend a course of twelve treatments for the purpose of instruction in its self-administration, and then to continue the treatment himself for a period of at least six months. Even very advanced cases, in which I have adopted this course, have

usually written enthusiastically after six months of self-administered treatment to say how greatly they have improved. This course is naturally not so satisfactory as keeping the patient under observation the whole time; but there are many cases in which the choice only lies between the auto-administration of the treatment or no treatment at all.

Hands, wrists, elbows, feet, ankles, and knees respond more readily to electrical treatment than the more deeply situated joints, such as the hips and shoulders in which parts considerable diffusion of the current occurs.

Certain forms of myalgia yield very readily to the heat of diathermy or to the muscular auto-massage resulting from the Morton wave current. Lumbago is generally regarded as due to a hypertonicity of the lumbar muscles, excited by the presence of toxins or other morbid process.

My own experience leads me to regard lumbago as due to a primary articular lesion or inflammation in the vertebral articulations, or to a peri-articular inflammation in the surrounding fibrous tissue, and to a secondary spasm of the lumbar muscles of a reflex nature which tends to fix and render immobile the affected vertebral region. It can be readily understood that the reflex relaxation or loss of tone, such as occurs in the quadriceps extensor after a lesion of the knee joint, is of a protective character: if, however, such a relaxation occurred when the vertebral articulations were affected, the condition of the patient would indeed be a parlous one; in this case a protective fixation of the affected parts is secured by a tonus reflex of the muscles.

Such a theory leads to the adoption of a double process in the treatment of lumbago, namely, first an application of diathermy to relieve the pain and the inflammatory process, and then the administration of the Morton wave current to remove any hypertonus of the lumbar muscles that may remain.

On this hypothesis the method that I recommend for the treatment of acute lumbago is a preliminary applica-

tion of diathermy of from 1½ to 2 amperes according to the size of the active electrode which should be regulated in accordance with the size of the area affected. The active electrode is placed over the area of the lumbar region affected, and a somewhat larger electrode is placed on the abdomen. These electrodes may be secured in place by the patient lying on his back on the active electrode and securing the indifferent electrode in place by his hands or by means of sandbags. If, however, such a method is adopted, the patient should be warned against suddenly raising himself from the active electrode when he feels the current too hot. If he does so a burn will probably result from the concentration of the current at the point of last contact of the electrode with the back of the patient. The patient should be always told to inform the operator when the current becomes too hot in order that its strength may be suitably reduced and a burn avoided. This treatment should be continued for 30 to 40 minutes, and should be followed by 10 minutes of the Morton wave current.

Acute stiff neck may be regarded from the point of view of treatment as 'lumbago' in the cervical region, and may be treated on similar lines to that complaint with a suitable reduction of the amount of the diathermy current and a much modified and reduced Morton wave current.

The swelling and induration of the legs, consequent upon phlebitis and other causes, is very amenable to electrical treatment. The best method in these cases is the surged Watteville current; its strength should be sufficient to excite weak but perceptible contractions of the muscles; it should be rhythmically surged with suitable interruptions. The legs should be placed in a leg bath with feet resting on the electrode. In addition to the effect of the muscular contractions there is a direct stimulation of the tissue cells in the legs by the recurrent hydrogen ion concentration, and this no doubt contributes largely to the production of the excellent results obtained from this method of treatment.

Diathermy will quickly and with certainty relieve the

acute pain of gout. We rarely see nowadays the old-fashioned typical and classical cases of this disease. I have, however, treated two such cases by electricity. The following case is typical of both: the patient, a country squire with a personal and hereditary history of port-wine and gout, with thickened finger and toe joints, with frequent exfoliations of sodium biurate, was sent to me for electrical treatment to relieve the acute pain and swelling in his toes, feet, and ankle-joints, from which he was suffering. The patient had recently had a severe attack of gout attended by a high temperature, headache, general malaise, and constitutional symptoms. On the subsidence of the high temperature, and the disappearance of the general symptoms, swelling and very acute pain became localized in the ankles and feet and he consequently came immediately for electrical treatment. The pain was immediately and completely relieved by diathermy, but on returning home the general constitutional symptoms reappeared with high temperature.

Of course two such cases are insufficient to warrant any generalization, but the following explanation of the phenomenon recorded is tentatively suggested.

During the high temperature the uric acid was in solution in the blood stream and excited general symptoms: on a reduction of the temperature occurring, the uric acid crystallized out in the extremities where the circulation was least active and the temperature lowest, and, before its formation into the relatively inert sodium biurate, exercised a painful and irritating effect in those regions.

The heat from the diathermy redissolved the crystallizing uric acid, it was reabsorbed into the blood stream, and again excited constitutional symptoms.

The practical conclusion to be deduced from this reasoning is as follows: that diathermy acts so efficiently in the relief of gout that, when given immediately after an acute attack, it should be administered with caution and its application should be combined with some form of treatment for the elimination or neutralization of the uric acid.

## CHAPTER II

## THE DISEASES AND INJURIES OF THE NERVOUS SYSTEM

ELECTRICITY is of very limited service in the treatment of diseases of cerebral origin; it may occasionally be of use in treating some of the sequelae which arise from these diseases, but its action then is only symptomatic and indirect.

In diseases of the spinal cord electrotherapy is more likely to produce benefit, owing to the greater accessibility of the parts; but even here very little has been achieved at present, though there is reason to hope that such a disease as insular sclerosis may, with an improved technique, be favourably influenced by radiotherapy. It is in connexion with the peripheral nerves, both motor and sensory, that our work is mainly concerned.

### The Electrical Treatment of Anterior Poliomyelitis and the Peripheral Lesions of Motor Nerves

These two forms of peripheral nerve lesions, though differing very widely in their pathological origin, nevertheless in reference to their treatment form an electrotherapeutic syndrome, and so can be most conveniently discussed together.

In the Great War the treatment of peripheral nerve lesions presented one of the most important problems, when considering the restoration of the disabled soldier to a life of functional usefulness. The enormous number of such injuries afforded those engaged in their treatment a practical experience never before approached. An experience such as this naturally led many of those not immovably obsessed by preconceived ideas to modify considerably their former views. Personally, I must confess that, as the result of experience and observation, I have departed somewhat from the views I originally put

forward. The line originally adopted in reference to the electrical treatment of peripheral nerve lesions was somewhat as follows: 'The function of a muscle is to contract; when the motor nerve is severed it is impossible for the patient to make it contract voluntarily. Consequently those muscles whose nerves have been divided are rendered functionless; they hang like hammocks from their attachments, waste and toxic products accumulate in their substance, fatty degeneration takes place, and finally, if untreated, conversion, more or less complete, into fibrous tissue occurs, so that by the time the nerve has regenerated, the muscle has lost all contractile power. Our object therefore in the treatment of paralysed muscles is to make them contract by means of the galvanic current, and so, by exercising their function, to maintain their contractility and nutrition while the nerve is undergoing the process of regeneration.'

Looking back on my war experience, I am inclined to think that there are two fallacies, at least, in this argument. The first fallacy is that one overlooks the difficulty, or even the impossibility, of exciting a really efficient contraction in a muscle, the nerve of which has been completely severed.

Experience shows us that the density of current needed to excite a contraction in such a muscle is very great, and that the resulting contraction is confined to a few fibres; such a contraction occurring with the single isolated shocks of the galvanic current can have but little influence on tissue drainage.

The second fallacy is that the maintenance of the muscle's condition is solely dependent, from the electrical point of view, on the excitation of contraction.

No doubt in treating such cases on the theory stated, and administering strong electrical currents to excite such contractions, we did very considerably contribute to the maintenance of the muscle's condition; but the greater part of such benefit was probably due to the heating effects of the current and the stimulating influence of the

hydrogen ion concentration, which resulted from the use of interrupted galvanism of high intensity.

My more recent experience, the outcome of contrasting several cases of complete nerve lesion treated by different methods, is that the surged sinusoidal current, to the strength necessary to excite faint contractions in the neighbouring healthy muscles, yields the best results in these cases. It is probable that, obsessed by an orthopaedic ukase, too much importance has been attached by electrotherapists to the idea that harm is done to the paralysed muscles by the over-action of the healthy muscles during electrical stimulation. The vigour of such contractions is not such as to lead to over-stretching, and the effect of the contraction of the healthy muscles is to bring an increased blood supply to the part. Certainly the faint tremor excited in the healthy muscles by a sinusoidal current of the strength advocated can have no such harmful action.

In the treatment of peripheral nerve injuries on the point of recovery, the proposition is an entirely different one. The period at which the end-plate is recovering is the time at which harmful fatigue of the nerve or its end-plate is most easily produced, and it is very important that electrotherapists should fully realize this point. The teaching usually given is that as soon as a faint faradic response occurs in a formerly paralysed muscle the galvanic current should be abandoned for the faradic. Nothing is calculated to produce more harmful results at this period. At a time when the end-plate is most susceptible to fatigue, a stimulus occurring fifty times a second (the faradic) is suddenly substituted for one occurring only once or twice a second (the interrupted galvanic). This period of the recovery of the end-plate is the time for the application of the Lapicque current, which stimulates, at a low intensity, single and isolated contractions in the recovering muscles without any contraction occurring in the neighbouring healthy muscles. The return to voluntary power is very much expedited by this method of

Lapicque. Its beneficial action is largely due, I think, to the fact that the patient sees for himself the isolated contraction slowly occurring in the formerly paralysed muscle, and this materially assists him in applying voluntary effort to intensify or produce this movement.

The results obtained by the treatment of peripheral nerve lesions during the war clearly show that by suitable electrical treatment, not necessarily by the excitation of contractions, we are able to influence favourably the healing of the wound, to heal trophic sores, or to prevent their occurrence, to improve the condition of the skin, replacing the dry, harsh, scaly condition associated with untreated nerve lesions by a state more nearly resembling the normal, to aid the nutrition of the affected limb by increasing its temperature and accelerating its circulation, and thus, though we make no claim to affect directly the regeneration of the nerve, we must, nevertheless, indirectly influence that process by inducing in the limb a condition more favourable to regeneration.

These are not merely subjective symptoms favourably interpreted by too enthusiastic electrotherapists: actual measurements of the limbs showing increase in girth, reappearance of the growth of hair on the skin, the diminution in the milliamperage of the galvanic current required to excite a contraction, the increased formation of callus in ununited fractures, radiographically demonstrated by Dr. Barclay as taking place after suitable electrical treatment, are objective signs which admit of no other interpretation than that the nutrition of the tissues, lowered by injury or disease, can be greatly improved by modern electrical methods.

### The Electrical Treatment of Anterior Poliomyelitis (Infantile Paralysis)

Recent researches into the morbid anatomy of infantile paralysis have shown that 'we can no longer regard it as an affection limited to the anterior horns of the grey matter of the spinal cord, but a widespread polio-myelo-

encephalitis with meningeal complications. The changes in the spinal cord are very characteristic. The meninges are moist, the pia is hyperaemic, sometimes with small capillary haemorrhages. On section the cut section bulges, the grey matter is hyperaemic, appearing as a reddened H, or the redness is limited to the anterior horns, which may show spots of haemorrhage' (Osler). The micro-organism is a minute globoid body, which occurs in pairs and is a filter passer. On inoculation into monkeys, paralysis occurs, and the organism can be removed from the animal's tissues and grown in pure culture.

The organism reaches the central nervous system through the peri-neural lymphatics and then becomes fixed in the grey matter. The path of entry is demonstrated by the fact that monkeys can be infected by local injection into a nerve trunk, whilst division of the nerve trunk above the site of inoculation will prevent infection.

The pathological lesion is an acute inflammation of the grey matter of the nervous system: probably due to a direct toxic action on the nerve cells, which in parts become destroyed. The piamater is infiltrated with leucocytes (lymphocytes). The blood vessels are surrounded by these lymphocytes and show what is termed 'cuffing'.

Neurophages may be seen by the aid of the microscope actively absorbing the nerve cells of the grey matter. The affected portion of the grey matter may be completely destroyed; it may, on the other hand, recover partially, or wholly. The muscles supplied by the affected portion will suffer according to the amount of destruction of the nerve cells. The resulting degeneration of the muscles may be either fibrous or fatty.

If, as the above very brief résumé of the pathology of anterior poliomyelitis indicates, the lesion of the nerve cells is due to the direct action of the neurophages absorbing the grey matter, physiotherapy would appear to hold out but little hope of arresting the disease or checking the morbid process in its early stages. On the other hand, such remarkably good results have been recorded from the

treatment of this condition in its initial stages by Bordier's method of combined radiotherapy and diathermy that it would appear that the decompressor action of the former method, by relieving tension and facilitating drainage in the inflamed area, must have a marked effect in limiting the initial injury to the nerve cells.

According to Bordier (1) 'the action of X-rays is to contend against the sclerosis and the atrophy which tend to destroy the nerve cells near to the seat of the myelitis; but the improvement is brought about mainly by an indirect action on the peripheral oedema and on the pericellular infiltration: the inflammatory phenomena diminish and are resolved instead of extending and organizing themselves in the form of exudations which would finally end in destroying or definitely injuring a large number of nervous elements, such as happens when the disease is left to itself'.

Bordier regards the action of the diathermy, which he associates with the radiotherapy, as combating the muscular atrophy that ensues as the result of the hypo-thermia and deficient nutrient exchanges attending the early stages of the disease.

The method of Bordier has been largely practised in France, Italy, and in Spain; so far as I am aware, no serious trial has been made in this country of this treatment of infantile paralysis, although it is free from risk and has apparently yielded such good results on the continent.

Turano, (2) who worked in Rome under the direction of the late Professor Ghilarducci, has published 13 cases of acute anterior poliomyelitis, treated by radiotherapy: in his view the results obtained are 'perfectly marvellous'.

Somewhat less enthusiastic, but perhaps correspondingly more convincing, are the results and conclusions of Drs. Castells and Carulla (3) of the Faculty of Medicine of Barcelona.

These two doctors, the former an orthopaedist, and the latter a physiotherapist, struck by the claims of Bordier and Ghilarducci, decided to give the method a fair trial,

and on doing so they were promply convinced that they were able to obtain, by means of deep radiotherapy, an important improvement in the treatment of cases of infantile paralysis; and, as the result of further experience, they finally concluded that the advantages of the method, even if it did not result in a complete cure, were, nevertheless, very important; and they, moreover, found that the extension and intensity of the paralysis were appreciably and constantly diminished and reduced. These observers point out that, in regard to dosage, in the inflammatory stages, when many cells are undergoing mitosis, the X-ray dose is considerably less than is required in the later and sclerotic stage when the cellular activity is not so marked.

Drs. Castells and Carulla give the following résumé of their technique: 'Treatment should be undertaken as early as possible with penetrating radiation at a fixed focal distance: the dose should be more intense as the date of the infection is more remote: 40 to 50 % of the erythema dose, given in divided doses, in order that it may be better tolerated, on three or four consecutive days when the date of attack is less than a month or a month and a half. If the date of invasion is more distant, 75 to 85 % of the erythema dose should be given. It is necessary to repeat the dose 2 or 4 times in order to act on the residual inflammation or on the more resistant sclerosis. It would perhaps be well, even in cases that have undergone treatment promptly after the commencement of the attack, to give two final series of a dose of 70 or 80 % of the erythema dose. With a strong dose, especially in the two final series, it is necessary to allow the lapse of a month or even two months. If the dose is more than 70 % we do not consider it well to give more than three series. After the lapse of six or seven months from the date of infection, one can try the effect of giving a maximum dose, but only as a trial attempt.' Filters of 5mm. of zinc or copper are employed, a voltage of 200 kilovolts, at a focal distance of 40 cm. in order that the coefficient of penetration should be

as high as possible. The treátment is frequently attended by vomiting, loss of appetite, and perhaps a rise of temperature. These unfavourable symptoms quickly subside after the discontinuance of the treatment, but if the vomiting is troublesome, it is well to subdivide and space the doses.

It is clear that this form of treatment should only be undertaken by those experienced in the administration of deep X-ray therapy.

It is with the after-effects of anterior polio-myelitis that electrotherapy is chiefly concerned. The problem may be briefly stated as follows: that, either as the result of the subdural pressure, or as the result of the direct action of the virus, certain cells of the anterior cornua are affected to a varying extent. (1) Some are so severely affected that, no matter what treatment is adopted, no benefit will result. (2) Some cells are so slightly influenced that complete recovery will take place whatever form of treatment is adopted, or even in spite of treatment. The first class of case belongs almost entirely to the orthopaedist, whose function it will be to make the best of a very bad case. It is obvious that it makes very little difference into the hands of which class of legitimate practitioners the last-mentioned type falls. But between these two classes there is a very wide division, in which the number of cells and the number of nerve filaments recovering will depend upon the efficiency of the treatment adopted. The more efficient the early treatment by decompression, the fewer will be the cells destroyed: the more efficient the after-treatment by maintaining the nutrition of the paralysed limbs, the less will be the fibrotic changes in the muscles, and the more favourable will be the condition for the recovery of the nerve fibres in connexion with those nerve cells that have not been completely destroyed. It is with this intermediate class that electrotherapy is mainly concerned. The problem of the most efficient treatment of infantile paralysis in the chronic stage is practically identical with the treatment of peripheral nerve lesions. In both in-

stances treatment which is conducive to the maintenance of the circulation in the affected limbs prevents the occurrence of chilblains and trophic sores, preserves the temperature and increases nutrition, will be calculated to prevent fibrotic changes in the paralysed muscles, and will tend to facilitate the regeneration of the nerve.

The indications for treatment are plainly shown by the cold, flabby, and wasted limbs, and by the chilblains and trophic sores by which they are often covered.

It is unfortunately true that many of the leading authorities on infantile paralysis attach little or no importance to the action of electricity in this disease. But such persons know little or nothing about electricity, and often less about its application to medicine. They may sometimes admit that the faradic current will excite healthy muscles to contract and so may be of use in their development; but they are often ignorant that the interrupted galvanic current is capable of exciting contractions in paralysed muscles. They are unaware of the true aims of electrical treatment and the methods by which these aims are realized. What little experience they may have had of its use is derived from 'treatments badly directed, badly applied by unqualified persons, from treatments of insufficient intensity and duration, and applied with defective instruments' (Bergonié (4)).

It was to physicians of such a type that John Wesley (5) addressed his final appeal: 'That none of them would condemn they know not what: That they would hear the cause, before they pass Sentence: That they would not peremptorily pronounce against electricity, while they know little or nothing about it. Rather let every candid Man take a little Pains, to understand the Question before he determines it.'

To be fully effective, any form of treatment for the after-effects of infantile paralysis must be based upon an accurate electro-diagnosis. With children, Bergonié's method of simplifying the technique by testing the whole limb at one time, as for instance in the leg, by applying

one pad at the buttock and the other round the foot and ankle, will give sufficiently accurate information with a minimum of discomfort to the patient. The condenser method of testing, if the paralysis is not complete, will be more readily tolerated than the faradic and galvanic method. Where, however, the degree of degeneration is advanced, the large condenser stimuli required to excite a contraction will be found to be equally or even more painful than the galvanic.

An accurate electro-diagnosis enables an experienced electrotherapist to form a reliable prognosis, and he is able to predict from it, with reasonable accuracy, which muscles will improve and the extent to which they will recover their power. Such an examination affords the only reliable grounds upon which to base the line of treatment. The form of treatment will necessarily be different for a muscle reacting to faradism from that required for one which only responds with a flicker to strong galvanic stimulation. The former if treated by faradism will readily and quickly improve and return to its normal condition.

In the latter case no hope of improvement can be entertained from the excitation of muscular contraction, and attention must be directed to the maintenance of the nutrition of the limb. For the avoidance of deformity such a case should be placed under the supervision of an orthopaedic surgeon. Between these two degrees there is a wide range in the extent of disability found in cases of infantile paralysis, and only long experience will enable the electrotherapist to lay down the most suitable form of treatment and to predict its probable result.

There are one or two points which are especially noticeable in the electrical treatment of this disease. One of the most striking is the sudden improvement which almost invariably occurs shortly after the commencement of the treatment; it is almost as though there were some latent recovery lurking in the muscle needing only the electrical stimulus to reveal its presence. The hopes of the relatives

are often unduly raised by such an occurrence, and expectations of a speedy cure are thereby entertained, which are incapable of realization. Such an occurrence is usually followed by a more or less prolonged interval in which little or no improvement takes place, and the hopes of the relatives become correspondingly depressed, and the patience of the electrotherapist is sorely tried. Then a faint flicker is suddenly detected in a previously inactive muscle, and is soon followed by a decisive contraction, so the hopes of the friends are again buoyed up. And so the case proceeds with alternations of hope and despair, but steadily progressing towards the increase in the number and power of the movements.

The progress of such a case is invariably slow; a treatment of at least an hour's duration daily may have to be persisted in, with short intervals of rest, for a period of two or three years. But the time, trouble, and expense are well repaid by the results ultimately obtained. The following is an actual and typical case. An adult with a history of an attack of acute anterior poliomyelitis eighteen months previously, improved at first, but for the past nine months there had been no improvement. The legs alone were affected, and their muscles showed all variations from complete galvanic inexcitability to the faradic reaction. The patient was unable to balance himself or to stand without the aid of crutches.

Under prolonged treatment by intensive electrotherapy, followed by massage and re-educative movements, the patient gradually improved: he was first able to discard his crutches, and balance himself with sticks; later at the end of eighteen months' treatment he was able to balance himself and walk for a short distance without sticks. All the muscles, however, have not recovered voluntary power at the end of two years, and in many of those which have recovered voluntary movement the power is not normal; but as the result of the treatment the best is made of the muscles that have regained their nerve power, and the others have been placed under the most favourable

conditions for recovery. Contrast such a case with one treated by undue splintage and rest; and in the one case you will find a patient able to get about for himself, and in the other an invalid requiring the unremitting attention of a constant attendant.

One of the most important points relating to the effect of suitable electrical treatment in cases of infantile paralysis is that it develops to the full extent those muscles which regain their voluntary power.

Without the aid of electrotherapy the prognosis of infantile paralysis is as Bergonié says: 'toujours un avenir d'atrophie, de déformation des membres, d'appareils orthopédiques indéfiniment renouvelés, que l'on prédit à ces petits malades; en un mot: une vie d'infirme, d'éclopé ou de cul-de-jatte, avec, pour consolation, des remèdes auxquels on ne croit pas soi-même'.

Bergonié rightly goes on to point out that the prognosis and forecast of the result of the treatment depend upon the spirit which directs and the hand which applies it; in the same way as in a severe operation, the prognosis depends to a large extent upon the operative technique and the manual skill of the operator.

### The Electrical Treatment of Neuritis and Neuralgia

These terms are usually so loosely applied that it is impossible to differentiate between them: often when we apply the term neuritis there is no marked inflammation of the nerve, but merely a compression by a tumour, and when we speak of neuralgia, there is often present a very definite neuritis.

Neuralgia is not one single entity, but a syndrome characterized by pain distributed over the course of the affected nerve, 'the sensations provoked by the excitation of the sensory fibres being always subjectively referred to the peripheral extremities of the nerves affected' (Hallopeau).

As predisposing causes to neuralgia and neuritis we recognize any condition which may lower the general

health, such as under-nourishment, anaemia, and such states of health as are induced by alcoholic, lead or mercurial poisoning, &c.

Pain, a most valuable diagnostic and protective agent, is the invariable accompaniment of neuritis and neuralgia and is the essential part of these conditions that calls for the aid of the electrotherapist. As Valleix has pointed out, there are certain painful areas of special importance: these he enumerates as follows: 1. At the points of emergence of the nerve trunks. 2. The points where the nerve filaments traverse the muscles to reach the skin. 3. At the points where the terminal nerve branches distribute themselves in the skin. 4. At the points where the nerve trunks become very superficial. 5. Finally, according to Trousseau, at the point of the spinal promontories corresponding to the nerve roots affected.

Broadly speaking, pain is so invariably the result of some form of pressure that the main object of electrotherapy in the treatment of neuritis and neuralgia is the relief of some area of pressure.

This causal relationship of pressure to pain is well illustrated by the pain of an abscess or toothache, and its immediate relief on the removal of the pressure by the evacuation of the abscess or the extraction of the offending tooth.

Pressure from a constricting band may in the same way cause severe pain, which immediately ceases on the removal of the constriction; and probably there is no more terrible pain than that occasioned by the pressure of an aneurysm. Spasmodic pain is doubtless due to the tension or pressure excited by muscular contraction. It thus becomes evident that if the pressure occasioned by inflammation or constriction, or by spasmodic muscular contraction is relieved, the pain will cease. Thus in the treatment of pain, the relief of abnormal pressure becomes the first aim of the electrotherapist. With this object in view, diathermy is an agent of the greatest value, for it readily overcomes muscular spasm by the heat which it

generates, and also acts as a 'decompressor' in diverting the excess of blood from an inflamed area into the surrounding heated tissues. The effect of such an action, which is both immediate and capable of application to any part of the body however deeply situated, renders diathermy the method of choice in dealing with acute and recent lesions.

In dealing with more chronic conditions where the pain is caused by the constriction or compression exercised by fibrous tissue, better results will probably be obtained by the slower but more lasting effects of intensive galvanism. It is probable that an increased leucocytosis occurs in such cases in consequence of the treatment, which assists in the resolution of the fibrous tissue exerting the pressure. This 'sclerolytic' action is, however, a very limited one, and no very definite results can be hoped for from such treatment of large masses of fibrous tissue. An interesting case, showing the effect of pressure or constriction by fibrous tissue, occurred in my hospital practice during the war. A young soldier, enlisted solely for clerical work, was admitted to hospital complaining of severe and almost constant pain in the stump of his left leg which had been amputated for tubercular disease several years previously. The patient was evidently suffering from the pressure effects on the end of his stump, occasioned by a badly fitting bucket peg leg. A variety of electrical treatments yielded no results beyond slight and temporary relief of pain.

I therefore sent the patient to the surgical department for the exploration of the long saphenous nerve, to the former distribution of which the pain had been referred and the stump of which was tender on pressure. The end of this nerve was found to be thickened, and on its removal was sent to the pathological department for examination: a report was returned to the effect that there was 'much fibrous thickening both in and around the nerve fibres'.

The pain was completely relieved for a short time; on

its subsequent return a further length of the nerve was removed, after which the patient was permanently cured. In this case the continued irritation from an ill-fitting bucket leg had set up inflammation in the nerve, resulting in the formation of fibrous tissue for some distance in and around the nerve trunk. Radiotherapy was the only form of electrical treatment which would have held out any hope of success; but in view of the accessibility of the lesion, excision was undoubtedly the best treatment. This case also affords an explanation of the difficulty occasionally experienced in dealing with old-standing cases of sciatica and other forms of neuritis.

Cervical ribs may exist for years without giving rise to symptoms of neuritis, and then a sudden strain, such as the wrench of an arm in alighting from a tram-car, may set up a neuritis attended with great pain in the arm on the affected side.

This pain can be much relieved by diathermy, and the inflammation and thickening may disappear with rest, although the predisposing cause remains unaltered and may subsequently lead to a recurrence of the symptoms. The following case of a hospital sister, illustrated by a radiograph (Fig. 27), for which I am indebted to my hospital colleague, Dr. Sankey, demonstrates this point. For as long as she can recollect, the patient has been unable to carry a heavy weight in either hand without exciting a feeling of discomfort in the arm employed. In 1917, after catching cold whilst bathing, she had a stiff and swollen neck, followed by her first attack of brachial neuritis. The left arm was the one affected on this occasion. The pain was acute for three weeks, but after a further period of complete rest for four weeks it cleared up. No recurrence of neuritis occurred until Christmas, 1920, when she wrenched her right arm severely in working a lift. This strain was immediately followed by some pain consequent upon the initial bruising; but no pain typical of neuritis occurred for the first few days; then very severe pain of a definite neuritic type developed in the right arm

and prevented her from sleeping. This pain was promptly relieved by diathermy, but invariably recurred upon the slightest use of the arm, and was only ultimately cured by a further period of complete rest.

FIG. 27. Dr. Sankey's radiograph illustrating case of double cervical ribs.

Neuritis may arise from a variety of causes. (1) The rheumatic type, due to exposure to cold, damp, draughts, over-fatigue, or exertion. (2) The traumatic type, due to pressure, wounds, the lacerations accompanying dislocation or fracture, injection of alcohol, ether, &c. (3) From the extension of inflammation from neighbouring areas, as in caries of bone. (4) Secondary to the over-fatigue of

central cells, as in occupational neuritis. (5) As the sequela of the action of the poisons of infectious diseases.

The prognosis of neuritis under electrical treatment depends upon the duration of the condition and upon the nature of the cause. A simple neuritis due to over-exertion or exposure to cold will in the majority of cases quickly yield to suitably applied diathermy. On the other hand, no expectation of a permanent cure of neuritis due to extension from diseased bone, &c., can be entertained until the cause of the trouble has been removed. It is probable that more speedy cures will result when the inflammatory condition is peri-neural than when it is interstitial or between the nerve bundles. An accurate diagnosis, not only of the cause but of the exact situation of the lesion, is essential to successful treatment. In brachial neuritis, for instance, the location of the pain is very rarely the situation of the lesion, and to apply diathermy, as is so often done, through the painful area, is likely to produce no benefit.

In the majority of cases of brachial neuritis due to cold or exposure, the lesion is, I believe, in the cervical region, and is probably the result of pressure on the inflamed and swollen nerve trunk as it passes through the unyielding canal formed by the extension of the dura mater which envelops the posterior nerve roots as they approach the spinal cord.

In these cases the pain is referred to the distribution of the fibres so compressed. Often in cases of brachial neuritis a history can be obtained of a previous stiff neck; but the most suggestive evidence in favour of this view is obtained during the application of diathermy. The immediate effect of diathermy, especially if it is administered to nearly the limit of safety, is often to cause temporarily an actual increase in the pain. This is probably due to an initial increase in the tension in the part itself due to the heat, before the surrounding tissues become relaxed. This initial exacerbation of pain, which is of good omen as showing that the electrodes are applied over the right area, quickly passes away.

Now, when the electrodes are applied to either side of the neck and the diathermy current transmitted transversely through the cervical vertebrae, the first effect of the treatment is often to excite an increase of the pain in the arm at the usual painful spots, such as the elbow, &c. As these areas are in no way directly affected by the application of the current in such a direction, the pain in the arm must be referred, from the heated nerve trunk in the neck, to its peripheral distribution.

This theory of the 'radicular' origin of brachial neuritis is further supported by the fact that the best results are obtained in this condition by the treatment of that area. At the time I came to these conclusions I was not aware that the French electrotherapists had already arrived at a like conclusion in relation to the radiotherapy of sciatica, and that they had pointed out that the radicular area, the lumbo-sacral region, was the part on which the radiation should be applied in the treatment of that disease.

The special importance of the cervical region applies to cases of neuritis, arising from exposure to colds, draughts, and damp. In the treatment of the traumatic variety, an accurate history of the nature of the injury and the situation of the lesion are of primary importance.

In all cases of injury a radiograph should be taken, and a similar precaution should be taken whenever, from the unyielding nature of the case to treatment, or from a history of the onset following a strain, or in cases where there has been previous discomfort in the use of the arm, there is reason to suspect the presence of a cervical rib or band.

Neuritis of special regions presents points of special importance.

### Brachial Neuritis

The main points to be considered in this location have already been discussed. The following is a good routine treatment in a case which presents no special features.

Electrodes 10 cm.×5 cm. are applied and held in

position by the operator on either side of the neck, and a current of about 0·9 to 1 ampere administered for ten minutes. One of the electrodes is then bandaged to the extensor surface of the flexed forearm, immediately below the elbow joint, the other electrode is held over the lower cervical and upper dorsal spines, rather to the opposite side to that of the affected arm, and a current of about 1 ampere, varying slightly in degree with the diameter of the arm, is passed for five minutes. Next the electrode at the elbow joint is changed for a hand electrode which is held in the hand of the affected side, whilst a current of 0·5 ampere is passed for five minutes, or until the heat at the wrist joint becomes too great to be tolerated without discomfort. In this manner the nerve is treated throughout its whole length, and in each of the three applications the cervical region receives a treatment. The application of diathermy may be followed by the static breeze, the high-frequency *effluve*, or the ultra-violet light; each of these owes any benefit it may produce to the counter-irritation which it excites.

Where the patient is much exhausted from the constant pain, or where there has been much sleeplessness, much benefit will usually be obtained from the static charge. This treatment is especially useful when the more acute symptoms have passed away.

In old-standing cases of brachial neuritis the best results may be sometimes obtained from the more slowly acting, but more lasting, action of intensive galvanism. A thick pad, about seven inches × five inches, is bandaged to the back with its centre over the spine of the seventh cervical vertebra, the affected arm is placed in an arm bath, and a constant current of 40 to 60 ma. is passed for forty minutes or more.

Often this treatment may be advantageously preceded by a diathermic current to a comfortable intensity of warmth, passed through the same rheophores and pads for ten minutes prior to the application of the galvanism. In very old-standing cases the best results will be obtained

from the radiotherapy with a penetrating radiation over the lower cervical and upper dorsal vertebrae administered in the manner described below in the treatment of sciatica. The modern tendency among French physiotherapists appears to be to employ radiotherapy more and more in the treatment of all forms of neuritis.

### Sciatica

This term is usually applied to cover such a variety of conditions that, as ordinarily used, it connotes little more than 'pain in the neighbourhood of the leg'. At very short intervals two patients, the one a doctor, the other a clergyman, came to me for electrical treatment for pain attibuted to sciatica; in each instance, on examination, the pain of the alleged sciatica proved to arise from acute appendicitis.

Often the so-called sciatica is in reality sacro-iliac trouble, or disease of the hip or knee joint, or one of many other conditions.

True sciatica, or neuritis of the sciatic nerve, presents many points in common with brachial neuritis; but in the former the affected area is more deeply situated, and consequently more inaccessible to physical therapy; and it is moreover so surrounded by ligaments and other fibrous structures that the fibrositis accompanying the complaint is usually more extensive and difficult to deal with.

The trans-vertebral diathermic application, which is so effective a method in brachial neuritis, cannot be imitated in this region by a corresponding application of the current concentrated upon the lower lumbar and the sacral vertebrae. A modification of the treatment consequently becomes necessary.

The method I usually adopt in the treatment of a case of neuritis of the sciatic nerve has already been outlined in the chapter on the continuous current. A large pad of several thicknesses of Turkish towelling, soaked in a 2 per cent. solution of common salt, is applied over the lower lumbar and the sacral vertebrae, also covering most

of the buttock on the affected side; this is then covered by a large tin or other electrode and attached to one pole, usually the negative, of the source of supply. The leg on the affected side is enveloped in a pad of similar material and similarly prepared, from the foot to the upper third of the leg, and a metal electrode is applied to the pad over the sole of the foot. At one time I applied a long metal electrode extending round the foot and nearly up to the upper limit of the lower pad; but I abandoned this technique as I found that the greater part of the current travelled up the electrode, and concentrated at its upper limit, where it was liable to occasion electrolytic burns. Confining the electrode to the sole of the foot leads to more even diffusion of the current, and hence tends to prevent burns.

The treatment should be continued for at least forty minutes, and an attempt should be made to reach an intensity of 100 ma. I usually precede this treatment by five to ten minutes' application of the diathermic current, utilizing the same pads and electrodes; about 0·5 ampere is sufficient to produce a comfortable feeling of warmth in the leg. This amount of diathermy should not be exceeded, its object being to raise the temperature at the outset more quickly than it would be raised by galvanism, and only to raise it to such a point as can be maintained by galvanism. The treatment should be followed by massage, and if there is much stiffness, by gentle movements.

By such a method it is usually found that a very large proportion of cases of sciatica, arising from simple causes, such as damp, cold, or exposure, are cured in about twelve treatments. The action of the treatment and the way in which these results are produced have already been dealt with in the chapter on the action of the constant current.

When we consider the morbid anatomy of sciatica, the duration of some of the cases before they come for electrical treatment, and the multiplicity of causes to which this form of neuritis is due, it is not surprising that we occasionally find cases which fail to respond to treatment. The

anatomical relations of the posterior or sensory roots of the spinal nerves have an important bearing on the causation of neuritis. In their path from the ganglion to their entrance into the spinal cord they are enveloped in a dense unyielding prolongation of the dura mater from the spinal cord, and they are, moreover, covered with a fine network of vessels. The course of the lower spinal nerves is more oblique than that of the upper nerves and hence they are for a longer distance in relation to this extension of the dura mater. The fifth lumbar nerve (the lumbo-sacral cord), as Barré and Gunsett have pointed out, has 'in particular a true canal, the walls of which wrap themselves round the nerve'. These anatomical points are of special importance in relation to sciatica; for, as Barré and Gunsett have inferred from their anatomical investigations on the course of the posterior nerve roots, it is easy to understand how 'the least venous congestion, the least tissue inflammation, the least periostitis, and the smallest osteophyte may exercise a direct influence on the nerve'.

Under such conditions as these it is easy to understand that small doses of X-rays should have a beneficial decompressing action owing to the high radio-sensibility of the active cellular mitosis that accompanies such inflammatory conditions as those indicated.

Radiotherapy is in no way antagonistic to the other physical methods, such as diathermy or galvanism, with which forms of treatment it may often be usefully combined. It should be regarded as a very valuable addition to the equipment of the electrotherapist, upon whose judgement and experience the selection of the best method or combination of methods must depend. The importance of an accurate diagnosis, not only of the nature of the complaint, but also of the exact situation of the lesion is very apparent; for it may be laid down as a general rule in the treatment of sciatica, that, if the lesion is radicular, then radiotherapy is the method of choice; but, if it is peripheral, then one of the other methods will be indicated.

When the inflammatory exudates have in old-standing

cases become organized, and even the nerve fibres themselves are being destroyed and replaced by fibrous connective tissue, other forms of treatment are not sufficiently powerful, and recourse must be made to radiotherapy. For 'we can to-day assert that X-rays not only possess of themselves an analgesic action, but that this effect is the outcome of a decompression. The same thing happens in the case of cancer of the breast, and in its cutaneous metastases; the relief of pain that we observe in such cases, after an exposure to X-rays, can be attributed to a dissolution of the neoplastic lumps, and to a consequent freeing of the compressed nerve branches. This resolution action can be observed in cases other than neoplasms.

'The regression noticed in periadenitis, the increase in the amplitude of movement in certain cases of ordinary or bacillary chronic arthritis, are examples of the same kind. We see it also in certain cases of pachymeningitis.' (Babinski.)

Radicular radiotherapy of the sciatic nerve appears to have been first practised by Freund, who in 1907 treated, by radiotherapy of the lumbo-sacral region, a patient suffering from cancer of the breast, who had developed an acute sciatic pain, attributed to a supposed metastasis in the spine. Freund obtained a complete cure of the sciatica in this case, and attributed the result to a hyperaemic action of the X-rays analogous to that of heat, which increased the circulation, and so by causing a more rapid and active lavage of the tissues, more completely carried away the inflammatory products—an explanation which is not in accordance with modern views. Bergonié, Inbert, and others had already treated neuritis successfully in other parts of the body by radiotherapy. The treatment by radicular radiotherapy has been recently elaborated by Cottentot and Zimmern (6); it is to the latter of these that we owe the term 'radicular radiotherapy', a term he introduced to specify the irradiation of that segment of the nerve which is included between its emergence from the cord and the plexus.

The technique of the French workers varies somewhat in the administration of this form of treatment: Zimmern adopts a penetration of about 8, 9, or 10 Benoist; a filtration through 2 to 4 mm. of aluminium; applied over the foramina of the fourth and fifth lumbar, and the first and second sacral vertebrae, the field of radiation also including the sacro-iliac articulation.

The French workers appear to be agreed that the best results are obtained from the application of small doses, such as $\frac{1}{2}$ to 1 H (5 H = 1 Teinte B Sabouraud), repeated every two days, followed by a rest of eight to ten days after an accumulated dose of 3 H has been administered. Delherm and Py employ rays of 6 to 7 Benoist, $\frac{1}{2}$ mm. Aluminium, and give 5 H in 3 doses. Laborderie gives 2 to 3 H at each séance through a filter of 1mm. Al. Weill uses first of all a filter of 2 mm. Al., then one of 4 mm., giving 6 to 7 H at each radiation. Afterwards with a 22 cm. spark gap, and a filter of 1 cm., he gives a single dose equal to 10 to 12 H. According to Laborderie (7), 'the observations reported do not show that the method of strong doses, which is not without danger, have given better results than the method of small doses. Preference should therefore be given to the latter method.'

The radiation should be directed as much as possible through the spinal foramina along the course of the posterior nerve roots; this permits of the patient being placed on his side, a far more comfortable position for a sciatic patient than lying flat face downwards.

The treatment is frequently followed by some immediate relief from pain, but such relief is only temporary, and in a few hours pain of a severe character may supervene, so severe indeed as to discourage the patient from a continuance of the treatment. I have found the occurrence of this exacerbation of pain a good omen, for cases so affected usually make a good recovery. The patient should be warned of the likelihood of this exacerbation of the pain, and should be informed that in due course these crises will become less severe and of shorter duration until a cure is effected.

I have found radiotherapy of special value in the treatment of recurrent sciatica, a form of the complaint that is especially resistant to the ordinary forms of treatment.

The Morton wave current is advocated by some writers as a very efficient agent in the treatment of sciatica. When the pain has disappeared, I have found this method of considerable service in the removal of any stiffness that may remain; but in the acute stages I have found it of little value.

As a constitutional aid to the treatment of sciatica, the diathermy or high-frequency condenser couch and the static charge have been recommended; the last named is the more likely to prove of value for this purpose. It should not be forgotten that exhaustion and a bad general state of health are predisposing causes to sciatica, and that the pain of the condition further exhausts the patient: a rest and change of air, after the pain has been relieved, are of great importance in completing the restoration to health and preventing a relapse.

After the acute pain of sciatica has subsided, there frequently persists a dull aching in the affected leg, which is induced or aggravated by prolonged standing. This is probably due to the residual lack of muscle tone, which throws the strain of maintaining the erect position of the body on the ligaments, owing to the inability of the flabby muscles to perform their proper functions. Such a condition is best treated by the surged Watteville current, or, if a suitable surger is not available for such treatment, by the Morton Smart method of graduated muscular contraction.

Treated by the above methods, it will be found that the results obtained are most satisfactory, but it must not be thought that every case of sciatica can be cured by electrotherapy, or even by any other means. Old-standing cases accompanied by much fibrous thickening round the sacro-iliac and hip joints will often obtain but little benefit, and even in recent cases, in rare instances, some deeply seated, peri-neural, or interstitial source of irritation may prove very resistant to treatment.

Reference to works on general medicine will show that sciatica is one of the very few conditions in which benefit may be hoped for from the application of electricity: but, when we read the method of application recommended by the authors, usually the application of one small electrode over the sciatic notch, the other, a small electrode moved indiscriminately over the thigh, a current strength of from 2 to 5 milliamperes, applied for five or ten minutes, we cannot help thinking that these writers must be unduly optimistic of the results likely to follow from electricity applied in such an inadequate manner.

## DISEASES OF THE NERVOUS SYSTEM

**Tic Douloureux (Neuralgia Quinti Major, Epileptiform Neuralgia, Trigeminal Neuralgia).** This affliction, which Sir Henry Head describes as 'the most terrible of all diseases', is most resistant to all ordinary forms of treatment. Its pathology is very uncertain and affords but little clue to the best line of treatment. The morbid anatomy described is of the most contradictory character. 'Many observations have been made on portions of nerves extracted by surgical operation, but up to the present without satisfactory results. Dana found no change in the nerve elements, but an endarteritis of the vessels of the nerve sheath. Putman found the same endarteritis, but also changes in the nerve elements and the endoneurium. Horsley and Rose found no changes in the vessels, but change in the nerve elements. Krause found here and there thickening of the nerve sheath, accompanied in one case by thickening of the nerve fibres. In all cases the arteries were normal.' (Head: *Allbutt's System of Medicine*, 1899.) Examination of the excised Gasserian ganglion has revealed no constant pathological lesion.

The most helpful basis upon which to formulate a course of treatment is obtained from the pathological view expressed by Mr. Basil Hughes (8): 'My own constant finding is a hypertrophic obliteration of the arteries of the ganglion itself due to hypertrophy of the circular muscular

coat. It is not a condition of endarteritis. The change is identical with that seen in the arteries of the feet in that particular type of Raynaud's disease associated with intense pain of an unbearable kind in which patients readily submit to amputation in order to obtain relief. Similar changes were seen in the arteries of men who suffered with trench feet and the accompanying erythromelalgia. This is the only change I have been able to find in the Gasserian ganglia of patients suffering from true tic, and it is of important significance. It suggests arterio-spasm, arterial cramp, a condition allied to angina which might suitably be called "arterial angina". It is an angeio-neurosis, brought about by some sympathetic unbalance.'

No hope can be entertained that any electrotherapeutic measure can exercise a curative influence on the deeper structures, such as the Gasserian ganglion: but the painful afferent impulses clearly originate in very superficial areas, 'a breath of wind, a slight touch on the beard or hair' being sufficient to start a painful spasm. The electrotherapist will best direct his attention to de-sensitizing the hyper-sensitive skin receptors.

Diathermy can probably afford temporary relief, but it is difficult to understand how it can bring about any permanent relief in this condition. On the other hand, galvanism, if administered with sufficient intensity and for a sufficient period, by the polar irritation that it excites, is capable of inducing a thickening of the skin and a lasting reduction of its hyper-excitability. This view is supported by the fleeting benefit that follows the administration of weak doses of the constant current, and the lasting improvement that is obtained when the treatment is administered in very strong doses to the full toleration of the patient for a sufficient period. By suitable administration of the constant current an apparent cure may result in many cases, a period of complete relief for ten years or more may be obtained in others, but in some cases a relapse may occur in a few months.

During these lengthy periods of freedom from pain, the

patients are in a perfectly normal condition and are able to carry on their professions free from the troublesome sequelae which are consequent upon the more radical treatment of this complaint.

The other methods of treatment are by drugs, such as morphia, the effects of which are only temporary, and the repeated doses necessitated are certainly calculated to lead to the establishment of the drug habit. Gelsemium often gives temporary relief, but even to obtain this it must be pushed till numbness, or tingling, and perhaps vomiting supervene.

Alcoholic injection has been tried by a variety of technique, but the relief obtained is often transient and the procedure is certainly not without danger. Some of the best results obtained by this method are those recorded by Mr. Percival Mills (9). In fourteen of the twenty-five cases treated pain recurred after an average duration of relief lasting one year nine months. In the remaining eleven cases relief had been experienced for a period varying from one to five years at the time of writing.

Other writers have described alcoholic injection as but palliative and temporary. A patient, writing to me in reference to undergoing treatment by intensive galvanism, thus describes his experience of alcoholic injection: 'I have been a great sufferer for six years from trigeminal neuralgia and have undergone many kinds of treatment with no success. Two years ago I had an alcohol injection by Dr. . . ; this failed, and after a month, I had a second one—with the result that I have had no spasms since, but on the other hand have never for one moment been free from pain . . . I have been expecting a spasm any old time, as the trigger zones started tapping some months ago (my alcohol injection is now more than two years old), and the nurses in . . . told me that every patient returned for treatment *within* two years. I have never been out of pain for those two years—but it is pain that is bearable, and becolours part of one's life without affecting one very severely—but (and I am not at all a coward where

pain is concerned) these spasms were devastating and terrified me.'

The most certain cure for tic douloureux is undoubtedly the operation on the Gasserian ganglion by the Krause-Hartley operation or by one of its modern modifications. This is, however, so severe an operation, and one which, though perhaps not directly dangerous to life, is yet frequently followed by such serious results, namely the loss of the sight of one eye, hemiplegia, &c., that it should only be undertaken in very severe cases after other methods of treatment have been thoroughly tried and have failed to give relief.

I have tried ultra-violet radiation in two cases of tic douloureux, but the intense exacerbation of pain which followed its application in each case led me to abandon any further use of this method. The increase of pain following the application of U.V.R. is in accordance with the angeio-neurosis view of the pathology of this complaint.

Radiotherapy has been advocated by some French writers for the treatment of tic douloureux. I have tried it in a few cases without any benefit resulting; possibly the French employ a more penetrating radiation and so obtain a direct and favourable action on the Gasserian ganglion.

In the treatment by intensive galvanism, a thick pad, resembling half a mask, is cut to fit the affected side of the face, omitting the eyes and the nasal and oral orifices. A constant current of from 40 to 80 ma., or even more, is administered for at least half an hour with the patient in a recumbent position. Great care should be taken to increase and decrease the strength of the current very gradually.

The relatively low electrical resistance of the skin of the face enables a high intensity of current to be employed, under due precautions, without risk of an electrolytic burn, and in severe cases the risk of a blister should be incurred in preference to the administration of too small a current.

The indifferent electrode and pad should be of large

size, and may be placed in any convenient position: the arm of the opposite side affords a suitable line of force. The best source of current supply is from a battery of dry cells or accumulators regulated by a resistance: but, with a suitably designed water resistance, the current can be obtained safely and conveniently from a D.C. main.

My own results from treatment by the constant current have been as follows:

1. A man, aged about 65, a private patient, treated during 1912. History of tic for several years. Two courses of 'ionic medication' with the salicylic ion were given with only slight and temporary benefit. The failure in this case was due to the administration of insufficient current given under the erroneous impression that it was the specific action of the salicylic ion that was the curative factor.

2. Female, private patient, aged about 64. Very severe attacks for many years, totally incapacitating her. Had been previously injected with alcohol by a well-known surgeon with no relief. After the administration of thirty-three galvanic treatments, 60 to 80 ma. for thirty or forty minutes, there was freedom from attacks for ten years, and the patient was able to lead her normal life during this period. She then moved into a new and very draughty house, pain recurred which was relieved after a further course of twenty treatments, and six months afterwards, she is now reported to be free from pain.

3. Female. Private patient. Aged 20. 70 to 90 ma. Treated during 1920. Has had no relapse and has remained perfectly free from all symptoms.

4. Female. Private patient. Aged about 45. Treated 1925–6. Prolonged course. Reports May 1928, that she is very much better, occasional slight attacks, but she has been able to wear her false teeth since Christmas, a thing she had been unable to do since the attacks began.

5. Female. Hospital patient. Aged 77. Had suffered very severely from tic for over thirty years. Treated 1922. The treatment was interrupted by several attacks of

bronchitis. Severe pain has now entirely ceased, but she occasionally has slight spasms.

6. Female. Hospital patient. Aged about 40. Duration of illness five years. Treated 1924. When last heard of, February 1925, was quite free from pain. No further history obtainable in this case.

7. Female. Hospital patient. Duration five years. Treated from November 1924 to January 1925. When last heard of was free from pain.

8. Hospital patient. Aged 61. Treated March 1925. The pain in this case yielded to the treatment, but recurred in the spring each year, yielding on each recurrence to another course of treatment.

9. Male. Private patient. Aged about 50. Duration since 1922. Injected with alcohol, 1924. ('The only result was that I was very bruised, with two black eyes, and the pain worse for some weeks'.) In the spring of 1926, he received treatment from an osteopath: 'seemed to have no great effect on the tic'. This patient received three or four courses of treatment by galvanism from July 1926 to January 1928: at each course, relief was 'obtained almost immediately, and the pain has never since reached the violence that it had in 1925'.

After the last treatment, however, the pain recurred after a shorter interval of freedom, and the patient decided to undergo another injection of alcohol at the hands of a more experienced surgeon than had previously treated him. The affected side of his face is now quite insensitive and at present entirely free from pain, but it is too early to speak of the result.

10. An old and extremely feeble man, liable to recurrent attacks of bronchitis, with severe pain resembling in most respects that of tic douloureux, received two courses of intensive galvanism with only slight and temporary benefit. Each course was interrupted by an attack of bronchitis. The pain in this case appears to have been set up by a severe blow on the head which necessitated the removal of the eyeball on the affected side.

The traumatic origin in this case may have rendered this patient less suitable for treatment by intensive galvanism than the cases of more idiopathic origin, as the trouble may have been more due to pathological changes in the Gasserian ganglion, the direct result of the injury, than to increased excitability of the skin receptors.

Dr. Dyson (10) describes other good results from galvanism in the treatment of tic douloureux, and the French electro-medical journals contain many references to cures obtained from similar treatment: it is indeed to the French workers that we owe the introduction of this method and the insistence on the importance of strong doses.

In view of the harmlessness and safety of the procedure it may be fairly urged that a full trial should be made of intensive galvanism before resorting to more severe and dangerous methods: if, however, after sufficient trial, intensive galvanism should fail, then the terrible suffering caused by this complaint certainly justifies the adoption of more radical and severe methods.

Neuritis and neuralgia may be divided into many subdivisions, but the method of treatment is the same in most of them. Care should be taken in each case to ascertain accurately the cause and seat of the lesion, otherwise failure will usually result. In herpes zoster, for instance, a disease of the posterior root ganglia of the spinal cord, the electrical treatment (diathermy is usually the most efficient form) should be applied over the spine at the level of the affected ganglia, instead of applying it, as is so often done, to the herpetic vesicles. For the treatment of the herpetic vesicles and the atrophic condition of the skin associated with them, U.V.R., of sufficient intensity to produce a strong reaction, is most useful and efficacious. I have seen one case, at least, in which U.V.R., administered at the first appearance of the vesicles, seemed to abort the disease.

Neuritis migrans or ascending neuritis will not be found to yield to the ordinary electrical treatment of neuritis: radiotherapy to the original seat of injury, and the Leduc

current along the course of the affected nerve are, however, deserving of a trial in this most intractable complaint.

In *coccygodynia*, great relief and usually a permanent cure can be obtained from diathermy applied in the right manner. A cylindrical metal electrode should be inserted into the rectum and attached to one terminal of the apparatus: a pad and electrode the shape and size of the coccyx should be attached to the other terminal and applied externally over the coccyx. In this manner the heat is concentrated over the affected part and should be applied to the toleration of the patient for about ten or fifteen minutes daily.

*Causalgia* differs so essentially as regards its electrical treatment from the usual forms of neuritis as to suggest an entirely different causation and pathology. Diathermy, which usually yields such marked relief in neuritis, aggravates the pain in causalgia. The condition results from wounds of nerves, and was fully described by Weir Mitchell about 1865. Wounds of the median nerve are by far the most common to be followed by causalgia.

The following is a typical case of severe causalgia which was under my care during the war. Wound of right forearm: the pain, which was too severe to permit of the electrical reactions being taken, was of a paroxysmal character; the distribution was chiefly in the fingers of the right hand, it was excited by any sudden noise or disturbance; an aeroplane passing overhead brought on the pains to such an extent that the patient was unable to go into the hospital garden or on the balcony. As the result of the pain he was unable to smoke, he had very little sleep at night, and his appetite became very poor. The patient was very disinclined to move for fear of exciting a paroxysm, on walking he balanced himself on his toes with his knees bent, and although his right arm was in a sling, he further supported it by holding the fingers in his left hand. The skin on the hand was glossy and shiny, the nails long and incurved. The fingers were semiflexed at the metacarpo-phalangeal, and fully extended at their pha-

langeal joints: they were closely and rigidly approximated, so as, it appeared, to give mutual support and splintage to one another.

From lack of food and sleep, and exhausted by the pain, he became thin and very careworn in appearance. Diathermy aggravated the pain without causing even the slightest temporary benefit. He obtained most relief by continually holding his hand under the cold-water tap in the bathroom, but the skin of his hand became so sodden from this procedure that the method had to be discontinued for fear of producing trophic sores. No form of drug, or other treatment, gave him any relief, until he was given weak galvanic currents, rapidly interrupted by a Leduc interruptor. He obtained immediate relief lasting for some hours from this treatment, which was given for twenty minutes morning and evening. After its adoption he quickly became a changed man; his careworn expression passed away, he ate and slept well, and rapidly put on flesh. He ultimately made a good recovery so far as the pain was concerned. Other cases of causalgia reacted in a similar manner, but cases of pain from nerves compressed or constricted by band received more relief from diathermy. So marked, indeed, was this difference in the reaction to treatment that information of diagnostic value was thereby obtained.

Causalgia is rarely seen in peace time, but such cases sometimes occur. A few years ago, an undergraduate, who had put his arm through a window and in so doing had injured his median nerve, was admitted into the Accident Ward of the Radcliffe Infirmary, Oxford, suffering from typical causalgia. All the ordinary forms of treatment failed to relieve his pain and the patient was consequently sent to the electrical department of the hospital: he was immediately relieved by the Leduc current, and after a short course of treatment was discharged completely cured.

I have suggested in an earlier chapter that the sudden and rapidly repeated stimuli, resulting from the use of

the Leduc interruptor, may produce, by the recurrent hydrogen ion concentration they induce, a condition of exhaustion in the already irritated sensory nerves, somewhat analogous to the fatigue in a recovering peripheral nerve when over-stimulated by the faradic current. In the case of the motor nerve, loss of function results, as shown by the temporary absence of faradic excitability: so in the case of the already over-stimulated sensory nerve, a loss of function may result with temporary cessation of pain. Whatever the explanation may be, Leduc has shown by experiments on animals that, by means of these rapidly repeated stimuli of very low current intensity, it is possible to produce progressively a condition of anaesthesia, sleep, coma, convulsions, and finally the death of the animal.

**Headache, Migraine, and Sleeplessness.** Certain types of headache are very quickly relieved by the static charge combined with the head breeze. The type of headache, associated with low blood pressure, due to exhaustion or overwork, is the kind most suitable for this treatment. The patient reclines comfortably in the static chair for a period of thirty to sixty minutes, during which time a negative charge is administered and attracts to the patient's head, by means of a suitable instrument, a positive charge from earth. In suitable cases the headache will have disappeared entirely at the end of the treatment. The benefit resulting from this treatment is due to the rise in the blood pressure it causes, and consequently cases of high blood pressure should not be treated in this manner.

Very good results in the treatment of migraine often follow from the application of diathermy, and in the milder forms of 'facial neuralgia' relief can frequently be obtained from diathermic massage. Dr. Howard Humphris, whose experience of the method is greater than that of its introducer, writes as follows in his book, *Electrotherapeutics for Practitioners*, (11) 'I have had striking success with diathermic massage of Turrell, i.e. with

the patient on the autocondensation couch and connected up in the ordinary way, and a current of 500 milliamperes flowing through his circuit.'

Electrotherapy is by no means a certain cure for sleeplessness, but there is a type of this condition in which the static bath and head breeze are most valuable applications. The cases of sleeplessness benefited in this way are similar to those cases of headache that derive benefit from a similar treatment, namely, cases due to exhaustion, worry, over-fatigue, and especially those cases of sleeplessness induced by the late and irregular hours entailed by too slavish a devotion to social pleasures and duties; cases also in which the patient is worn out with pain, is 'overwrought', or feels too tired to sleep. In such cases a short course of treatments from the static bath will often produce a complete cure.

Neurasthenia, where the blood pressure is low, 'pathological fatigue', is, as has already been pointed out in the chapter on the currents derived from the static machine, a condition which is usually benefited by the static charge and spinal breeze.

**Hysteria.** Except in recent cases of hysterical aphonia and functional paralysis of the flaccid type, I do not advocate the application of electricity in hysteria. In this condition electricity is frequently applied as almost a punitive treatment; this is exceedingly bad for the reputation of electrotherapy, and it is, moreover, as much calculated to harm as to benefit the patient.

In hysterical aphonia, however, of recent origin the success of faradic stimulation is generally very striking. A large indifferent electrode is placed on the back of the patient, or on any other convenient place, and a small active electrode is applied over the larynx. The patient is asked her name, she replies in a whisper, 'Mary Jones', she is told that when the current is passing she will be able to speak more loudly. The active electrode is applied, and the core of the coil is gradually sheathed, the muscles of the neck are thrown into contraction, and

the patient exclaims 'Mary Jones' more and more loudly, until normal phonation is attained. The patient leaves the hospital with a normal voice, and is assured that if a relapse occurs a repetition of the treatment will be attended with even more marked success. It is seldom that patients come for a second treatment, but occasionally they do so.

In the form of aphonia arising from shell shock, the above form of treatment, in my experience, invariably failed, and I quickly discontinued its use.

In the flaccid type of pseudo-paralysis, as has already been pointed out, the excitation of contractions in the flaccid muscles by means of faradism quickly convinces the patients that their limbs are capable of movement, and usually voluntary power is quickly restored.

In the contractures arising from shell shock I invariably found that electricity was worse than useless.

In local anaesthesia, or paraesthesia of the skin, electrical stimulation affords an efficient means of exciting counter-irritation. It may be applied by a wire brush from the finely wound secondary of the faradic coil, but is more effectively and conveniently administered by means of the disruptive static breeze.

In the occupational neuroses, such as writer's cramp, the one alleviative is rest, and neither electrotherapy nor any other therapy appears to exercise any direct influence on the complaint. Faradic stimulation and massage may be of service in some cases by tending to improve the secondary muscular wasting or stiffness which may result.

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## CHAPTER III

## DISEASES OF THE CIRCULATORY AND RESPIRATORY SYSTEMS

THE chief form of heart disease in which electricity is of service is that type in which the heart muscle is weakened by recent illness, or by inactivity, and in certain other types of fatty degeneration. In other words, the form of heart disease most suitable for electrical treatment is that which is likely to be benefited by graduated and suitably regulated exercise. Passive ergotherapy, as it has been termed, or generalized muscular exercise excited by the faradic current, both theoretically and practically, affords the ideal method in such cases.

The patient reclines in a comfortable chair composed of electrodes, and without any strain on his part, and with no expenditure of his nervous energy, each or all of the powerful muscles of the body are excited to contract with a force regulated by a resistance board, and to a range limited by superimposed sand bags. The speed at which the contractions take place, and their vigour, can be adjusted by the operator according to the requirements of the patient during the whole of the treatment with the greatest nicety and exactitude. The patient is continually under the direct observation of the operator, who can immediately moderate or stop the treatment on the slightest sign of exhaustion of the patient.

The effect of exercise in certain conditions of the heart has been frequently and favourably discussed in medical literature; and there is no need to dilate further upon the subject beyond pointing out that where graduated muscular exercises are needed in heart cases it can most safely, most efficiently, and most readily be obtained by the Bergonié method of electrically provoked exercises.

The following is given as a type of case specially suitable for this treatment.

A patient consulted me with a view to 'ionic medication' for vague pains, flying about the body, believed to be of a rheumatic nature, and for general weakness. The history showed that about six months previously she had an attack of rheumatic fever, since which she had not regained her strength. She was very short of breath and was unable to walk more than a few yards. Her muscles were very weak and deficient in tone. The pulse was quick, there was no cardiac murmur, but the heart sounds were muffled and distant. The pains were of too fleeting a character to be suitable for electrical treatment, and the main indication for treatment was clearly the need for improved muscle tone and general strength. A course of twenty treatments of generalized faradism on the Bergonié chair was given, during which the improvement was steady and uninterrupted, and at the conclusion of the course the patient was able to walk a mile and a half. She was then instructed to continue her own treatment by steady and regulated walking exercise.

Diathermy through the heart would doubtless afford speedy relief to the pain of angina pectoris, but the bulk of the apparatus debars its general use in this disease.

**High Blood Pressure.** Even among electrotherapists there is much divergence of opinion in regard to the value of electrical measures in the treatment of this condition. This lack of agreement is largely due to classifying conditions of an entirely different nature under the comprehensive title of high blood pressure. It is surely clear that the treatment of high arterial tension in cases where there are no signs of arterial degeneration or renal disease (the Hyperpiesis of Allbutt) must be essentially different from the measures necessary in cases of advanced arterial degeneration (Arterio-sclerosis).

In the treatment of the former category, H.F. currents are undoubtedly of great value; but in the treatment of the latter, though they may produce some temporary alleviation of the symptoms, they may, on the other hand, be harmful or even dangerous.

In illustration of these points, I quote the following three cases. 1. Hyperpiesis. A medical man, aged fifty-five. Patient states that his 'trouble first appeared in 1923 with heart trouble but not severe. Played golf regularly till February, 1925, when patient suffered from severe headaches and had to go to bed for over a month. B.P. taken and found to be over 190.'

This patient first consulted me on September 28, 1925; his B.P. was then 210 (Sys:). H.F. administered on alternate days. B.P. fell by steady gradations till October 26, when it registered 160 mm. It then began to rise again, often reaching 190 during November and December. On resuming treatment after Christmas the pressure again fell, keeping as a rule about 160, and only rising on two occasions above 180. During February there was a further reduction, and the patient terminated his treatment on April 9, 1926, at 144 mm. Later in this month he took up an important and arduous appointment, the duties of which he has since been able to carry out without difficulty.

This patient had received electrical treatment for his blood pressure before coming to me, and he had always noticed that he received little or no benefit from diathermy, but that the H.F. currents of tension invariably benefited him. I tried him with both currents and the results certainly bore out his previous experience. Before consulting me the patient had been thoroughly examined at a London hospital by the electrocardiograph, X-rays and other modern methods of diagnosis, and no physical changes had been found in his heart, blood vessels, or other organs. I attributed his condition to some form of intestinal toxaemia, and ordered him Plombière treatment which I think greatly contributed to his recovery, though the patient himself considered that the electrical treatment was the sole factor in his recovery.

2. Arterio-sclerosis with recurrent retinal haemorrhages. Blood pressure reduced, but haemorrhages recurred.

A lady, aged about fifty, with advanced arterio-

sclerosis, was sent to me for H.F. treatment with a view to the reduction of her high blood pressure in order to prevent the recurrence of the retinal haemorrhages from which she was suffering.

The blood pressure in this case was considerably reduced following the application of H.F. currents of tension, but the treatment proved a failure, as the retinal haemorrhages recurred in spite of the blood pressure remaining lower than formerly.

3. Advanced arterio-sclerosis. Sudden fall of pressure, following course of treatment, accompanied by alarming symptoms.

A lady, aged about sixty-five, with advanced arterio-sclerosis and B.P. 208, consulted me in March, 1922, on account of sleeplessness and severe and persistent headache. After twenty-one treatments by diathermy, the blood pressure fell to 190, the headaches were relieved and the patient slept well. She returned home to the country, and remained in relatively good health for two months, when the headaches began to recur and she returned to me for more treatment. I have unfortunately no record of her pressure on her return, but it was still high. Treatment was resumed on June 21, and after three treatments by diathermy the pressure suddenly fell to 145 mm. This fall was unaccompanied by any unfavourable symptoms, and daily treatments were continued until July 5. Two days after the cessation of the treatment a further reduction of the B.P. occurred to 130 mm. and was accompanied by alarming collapse, delirium, restlessness, and refusal to take nourishment. The patient remained dangerously ill for three weeks, and then made a slow recovery.

No unfavourable symptoms persisted, and the patient is reported to have enjoyed apparently good health until she died suddenly of heart failure in February 1928.

These three cases illustrate the good results that may be obtained by H.F. treatment in cases of hyperpiesis, the ineffectiveness of lowering the blood pressure in some cases of advanced arterial degeneration, and the danger of too

great a lowering of the blood pressure by diathermy in elderly cases of arterio-sclerosis.

In each of the cases mentioned a considerable fall in the blood pressure followed the treatment, but, on the other hand, I have treated many cases of arterio-sclerosis by H.F. currents without being able to effect any appreciable or lasting reduction of the pressure.

Many other writers have noted the superior results obtained from H.F. currents of tension over those obtained by diathermy, and the former is probably also the safer method, being less likely to lead to too sudden a fall of the pressure.

**Arterial Hypo-tension.** The low blood pressure associated with neurasthenia can generally be raised by a short course of treatment by the static charge and breeze in the manner already explained in the chapter on static electricity. Since, in addition to the immediate rise following this treatment, the stimulation of the afferent nerves of the skin leads to an increased activity of the suprarenal glands, it is reasonable to suppose that, as 'function makes structure', a certain degree of permanency should result from the treatment. The tonic effect of the static charge in cases where the general health has been impaired by overwork, fatigue, worry, or exhausting illness, is thus rationally and satisfactorily explained.

**Diseases of the Respiratory System.** Electricity has been but little used in the treatment of diseases of the respiratory system, but there undoubtedly exists a very wide field of usefulness for its employment in such cases. On *a priori* grounds there is every reason to believe that diathermy should exercise great benefit in such conditions as pneumonia, chronic bronchitis and emphysema, asthma, and pleurisy: and chronic empyemata should yield to the curative products of electrolysis in the same manner as other suppurative conditions, access to which is patent or obtainable by operative incision.

**Lobar Pneumonia.** Electrotherapists have for many years past been pleading for a trial of the high-frequency

currents in the treatment of lobar pneumonia and have frequently pointed out that many of the more urgent symptoms of this disease, such as the pain, dyspnoea, cyanosis, cough, would be relieved by the application of diathermy through the affected lung. It appears, however, that a trial of a method of treatment so clearly indicated was not made until January, 1922, when the first recorded application of diathermy was administered by Dr. H. Eaton Stewart, with the co-operation of Dr. Bryan, at the United States Marine Hospital, No. 21, New York. Dr. Stewart, in his monograph, 'Diathermy in its application to Pneumonia', thus describes the effect on the first case so treated.

'It was agreed that when accepted means of treatment had proven unavailing, diathermy should be tried in the first case in which there was otherwise apparently no hope of recovery.

'In January 1922 such a case occurred and the treatment by direct diathermy was started. The result in this first case was one of the most dramatic in the author's medical experience. The relief the patient received from severe pleuritic pain and dyspnoea was immediate. His cyanosis disappeared about seven minutes after the treatment was begun. The temperature began to fall immediately by lysis. He received from two to four hours' complete relief after this and each succeeding treatment, and made an uninterrupted recovery.'

Dr. Stewart emphasizes the importance of commencing the administration of diathermy as soon as possible after a diagnosis of pneumonia has been made and he points out that 'not a single case of pneumonia has been lost (so far as the writer is aware) in which the treatment has been instituted before the third day'. And he cautiously adds: 'This does not mean that cases treated immediately may not be lost, but it emphasizes the value of early and intensive treatment.'

The relief of pain, cyanosis and dyspnoea, which had been foretold by electrotherapists before a trial had been

made of this form of treatment, was fully achieved. Both the pulse and respiration rate in most of the cases showed a slight retardation, but 'the alleviation of no other symptom was more uniformly successful than in the case of cyanosis'.

By far the most striking, however, and perhaps the most significant effect of all, and one quite unforeseen, was the subsidence of the temperature by lysis instead of by crisis. 'In 97 % of the cases the temperature started down immediately by lysis' (Stewart). Such a radical change in the mode of termination of the disease certainly suggests that the application of diathermy in pneumonia, so far from being merely symptomatic, has a fundamental and direct action. For, since the 'crisis probably marks the stage of active immunity to toxins of pneumococcus' (Letheby Tidy), it would appear that this stage of active immunity takes place gradually when diathermy is applied instead of suddenly, and consequently diathermy has an influence on the stage of active immunity to the toxins of the pneumococci.

In a disease, such as pneumonia, in which the age, the mode of life, and the general state of health exercise such a profound influence on the prognosis, and in which epidemics of such varying intensity occur, it is a matter of no little difficulty to obtain statistical results of any value on the influence of new remedies. In this respect, however, Dr. Stewart was especially fortunate, as his cases, occurring for the most part in a seaman's hospital, included men in the active stage of life, mostly about thirty-five years of age, who led the same kind of life, and were exposed to the same temptations in regard to alcoholic and other excess. Dr. Stewart was able therefore by means of controls to institute a fair comparison between cases treated by diathermy and those in which the older methods were adhered to. The results showed that of those treated by diathermy, twenty-nine recovered, seven died, a mortality of 19·4 per cent.

Of those untreated by diathermy, twelve recovered, nine died, a mortality of 42·9 per cent.

Dr. Stewart states that 'one of the most vicious epidemics in the history of the hospital occurred in the winter months of 1923, at which time most of the deaths both in the treated cases and in the controls occurred'.

With the addition of other cases, treated by diathermy outside the hospital, a total of sixty-seven cases was obtained showing a mortality of 11·9 per cent.

Dr. Stewart concludes his book by remarking: 'Disregarding all of the very favourable reports from cases treated outside of the hospital we have yet a reduction in the death rate of 55 per cent. in favor of the group who received diathermy over that of the controls. Surely this figure is not without significance.'

The method of administering diathermy in these cases presents no special features. Thin metal electrodes, covering the greater part of the surface of the affected lung, are applied through the medium of soap lather with as little disturbance of the patient as possible.

A current of one and a half to two amperes is passed for twenty minutes, the treatment being repeated as the course of the disease demands.

The only argument that can be advanced against the employment of diathermy as a routine treatment of pneumonia is the contention that the instrument is too bulky for use in private practice and that it is not available in many hospitals and institutions.

At the present day, however, there are several efficient patterns of portable diathermy apparatus obtainable, and no hospital ward to-day can be regarded as efficiently equipped unless it is wired to take a current of 20 amperes, and unless it has a diathermy apparatus for bedside use.

**Bronchitis, Broncho-pneumonia, &c.** In private practice I have seen much benefit result from the application of diathermy in chronic bronchitis and broncho-pneumonia. Good results are also reported from its use in bronchiectasis, and emphysema. The pain of pleurisy can be readily relieved by diathermy.

**Asthma.** I have tried diathermy in several cases of

asthma and have usually found it relieve to a marked extent the distressing symptoms of this disease. It is doubtful, however, if the treatment has any fundamental action on the basic cause of the trouble. Ultra-violet radiation has been recommended in this complaint, but I have never obtained much benefit from its employment in severe cases.

The following were the first four hospital cases that I treated by diathermy.

The first case was a hospital patient with very advanced osteo-arthritis for which little relief could be afforded, but the severe asthma which was associated with it was very markedly relieved by diathermy.

The second case was that of a masseuse working in the hospital department, who suffered from asthma of a milder type; she derived more benefit from diathermy than from any other remedy.

The third patient came to the hospital for treatment for rheumatoid arthritis, but she expressed doubt whether she would be able to attend regularly owing to her asthma, from which she got no relief except by constant use of Himrod's powder and a nebuliser. After diathermy administered through the thorax, she was able for the first time for many years to dispense with her former remedies.

The fourth case was that of a boy in the hospital who obtained unbroken sleep at night as the result of the first one or two treatments, and was shortly able to leave the hospital, and attend as an out-patient for treatment.

In the application of the treatment the main point of importance is to apply it slowly at moderate intensity for a period of not less than half an hour at each application. Using large pads, antero-posteriorly placed over the thorax, the current intensity should not be such as to produce any sensation beyond that of comfortable warmth; this usually amounts to about 1·5 to 2 amperes provided that the pads are large and are evenly applied.

**Hay Fever, Horse Asthma, Coryza.** In these conditions

better results can be obtained from the H.F. vacuum tube than from any other remedy.

About six treatments usually suffice to effect at any rate a temporary and often a permanent cure: and the patient after treatment is able to sit in a hay field, or to enter a stable or ride a horse without the recurrence of any trouble.

The technique is quite simple, a flattened and slightly curved glass vacuum electrode is inserted up the nostril and held in position by the patient. A high-frequency current of tension is applied for a few minutes until the electrode becomes uncomfortably warm. The current is then turned off, the electrode introduced into the other nostril, and the procedure repeated.

The effect of this treatment is probably brought about by stimulation of the condenser sparks rendering the hyper-sensitive mucous membrane of the nose less sensitive to the irritation of pollen and other irritative products and substances.

Coryza may also be treated with very good results and a 'cold in the head' aborted by similar application of the H.F. vacuum tube. In this latter condition, the germicidal effect of the ozone, which is generated in a considerable amount by these tubes, probably contributes to the cure. I have compared the effect of the Gallois quartz tubes with the results obtained by the use of the ordinary vacuum electrodes, in a case of horse asthma and also in cases of coryza and have found the former the more effective.

Acute Laryngitis can often be speedily cured and the normal voice restored by diathermy applied through the medium of two moistened pads placed under electrodes held in place, one on either side of the larynx. A lady consulted me one morning in much distress because she had lost her voice and she had an engagement to 'broadcast' from '2 LO' in the afternoon. A short application of diathermy to the larynx completely cured the aphonia and she carried out her engagement in the afternoon without difficulty.

**Pertussis, Whooping Cough.** French electrotherapists employ the ozone and the nitrous oxide resulting from the electrical discharges of the H.F. apparatus as an inhalation for the cure of whooping cough and asthma. Nogier, in his book, *Électrothérapie* (1), gives a diagram of the apparatus, and summarizes as follows the results obtained by this method in the treatment of whooping cough: 'Although the ordinary duration of whooping cough is from two to three months, Bordier (2) and Vernay have shown that the fits of coughing can be entirely suppressed in two or three weeks by this treatment. Good results from the treatment have been systematically obtained in Paris hospitals for children.'

There appear, however, to be some grounds for suggesting that the action may be that of the nitric oxide and not of the ozone, for Bordier states that the best method of obtaining the ozone is by the *effluve* from the high-frequency apparatus, and that the static machine is 'un procédé illusoire de production d'ozone'; now, according to Silvanus Thompson (*Electricity and Magnetism*), the spark and brush discharge produce nitric oxide, not ozone, but the silent discharge of the influence machine and that of the induction coil are particularly favourable to the production of ozone. The question has some importance, for there are reasons for believing that workers in an atmosphere in which ozone and nitric oxide are present in appreciable quantity, as in some large electrical works, and in a hospital department in which a powerful static machine is frequently in use, are more immune to the infection of influenza than the public generally. I noticed this in my hospital department during a severe epidemic of influenza in which the nurses in the wards were infected in large numbers, but none of the workers in the electrical department, where a powerful static machine was in constant use, were attacked; until one of them was taken away to relieve the pressure in the wards, when she alone of the electrical nurses fell a victim to the infection.

An interesting point in connexion with the rival claims

for ozone and nitric oxide, as the therapeutic agent, is the fact that in certain districts it is the custom of the poor people to take their children suffering from whooping cough to the gas works to breathe the atmosphere there as a cure for the disease: also, during a recent severe epidemic, it was pointed out that the nitric oxide, for one finds but little ozone in the air at the gas works, at such places was useful in warding off attacks of influenza.

There is sufficient evidence to justify the trial of a powerful machine of the Ozonair type to produce gases, by means of electrical discharges, for the disinfection of lecture rooms, cinemas, &c., during an epidemic of influenza. The diffusive power of the electrically produced gases penetrates through the oral and nasal passages to the alveoli of the lungs, exercising a powerful disinfecting action throughout its whole path to a far more efficient extent than can be obtained from the less penetrating action of lotions, sprays, &c.

When the Simpson lamp for the production of ultra-violet radiation was first introduced, the inventor claimed great benefit in cases of lung disease from the inhalation of the fumes, given off from the fused wolframite; thereby he ingeniously diverted attention from the inconvenience caused by their smoky fumes; but when thoroughly tested at a London hospital no benefit was found to result from the inhalation.

### References

1. Nogier, *Électrothérapie*, 1917.
2. Bordier, *Précis d'Électrothérapie*, 1902.

THE static charge by improving the general health is of service in some cases of chronic dyspepsia. Diathermy will relieve gastric pain, and its use has been recommended in gastric ulcer, but there is a definite risk of exciting haemorrhage by its application in that condition; so it should be administered with great care and only in carefully selected cases. The action of diathermy in relieving the malnutrition resulting from chronic dyspepsia is discussed later.

In diseases of the digestive system, electricity is of most service in the treatment of the atonic forms of constipation. In the acute form of atony, or paresis of the intestines, which occasionally follows abdominal operations, the faradic or sinusoidal currents, efficiently applied with suitable intensity, will restore the tone of the abdominal muscles, and in this way will often bring about a cure. Habitual constipation is due to such a multitude of causes and conditions that no one remedy is capable of meeting all the indications for treatment.

The most common cause, perhaps, is injudicious treatment at the commencement of the trouble; when instead of trying to cultivate a regular habit of evacuation at a definite time of the day, or instead of treating the constipation by the correction of faults in the diet or mode of life of the patient, recourse is made to purgative drugs, in doses of increasing strength, as the mucous membrane of the bowel becomes progressively more resistant.

Chronic constipation of a most obstinate type is frequently associated in a causal relationship with lax and flabby abdominal walls, due in the first place to the neglect of rational treatment at a confinement or other cause. Associated with this condition there is usually a lack of tone in the intestinal walls with consequent flatulent distension. The rational treatment of such a condition is the electrical

method. Faradic stimulation should be administered in such a manner as to develop the muscles of the abdominal wall. It is useless to apply the current from a small coil by means of a small active electrode over each muscle, in turn, in a perfunctory manner. The treatment must be methodically and efficiently administered either by the method of graduated contractions, or, as I find much better in these cases, by means of the Bergonié chair. The back and seat of the chair form an indifferent electrode of one polarity, and the abdomen is covered with a pad and an electrode and is connected with the other pole. Treatment should be administered for at least twenty minutes daily, and it is with advantage followed by massage.

Although peristalsis of the intestines is inexcitable directly by electrical means, it may possibly be indirectly and reflexly brought about by condenser discharges of high voltage applied to the abdominal walls or through the rectum. With this object in view the induced current from the static machine should be applied in the following manner. The indifferent electrode is connected with the Leyden jar having a positively charged outer coating, and is applied to the abdomen through a large moist pad. A rectal electrode, preferably of the Benham Snow pattern which is retained in position by the patient sitting upon it, is connected with the outer coating of the other Leyden jar (negative charge) and is inserted into the rectum. The current should be surged to the easy toleration of the patient by gradually opening and closing the discharging balls of the apparatus.

Alternatively the treatment may be applied by means of the Morton Wave Current: in this case the current is most readily and effectively surged by the author's automatic method. This method is a very simple one, and the necessary apparatus only costs a few pence. An insulated rod—a dry stick will suffice—is attached to the top of the case of the apparatus, so that it projects over one of the discharging balls, when in a position of wide separation. A thin copper wire is led from the other discharging rod A (Fig. 28)

across the insulating stick B, and the thin copper wire drops vertically downwards, so that a weight attached to its lower end is in light contact with the discharging ball C.

While the weight D is in contact with the discharging ball C, no current passes to the patient. On slightly moving the discharging ball C, or giving the weight a slight tap with an insulated rod or dry stick, the current will begin to pass to the patient, and will become stronger as the

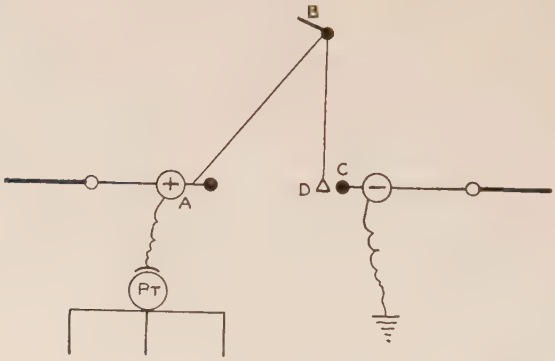


FIG. 28. Diagram to illustrate the author's method of surging the Morton wave current.

weight swings farther from the discharging ball, and weaker as it again approaches the ball in its return swing. The periodicity of the swing will depend on the length of the vertical wire, and the strength of the surge can be easily regulated from an almost inappreciable current to the patient's full toleration by the adjustment of the discharging ball C.

Mucous colitis is often benefited by a combined method of lavage and galvanism. The elaboration of the technique of this method is due to Dr. Curtis Webb. He connects a large pad of Gamgee tissue, thoroughly moistened with a 2 per cent. solution of sodium bicarbonate, to the negative pole of the source of supply. The positive pole is formed by a wire spiral, covered by a rubber tube, perforated at its lower part, connected to a douche can containing about

2 pints of 2 per cent. solution of sulphate of zinc. This rectal tube is well oiled and introduced into the rectum. When about half a pint of the solution has distended the lower bowel, the constant current is gradually turned on until a maximum of 15 to 20 ma. is reached. The treatment is continued for 10 or 15 minutes, and during the whole of this time the solution of sulphate of zinc slowly flows. From this combined method of lavage and galvanism good results have been recorded. The main action would appear to be that of the nascent oxychloride of zinc formed by the electrolysis at the positive pole: such an action would certainly be calculated to be beneficial in certain diseased states of the mucous membrane of the lower bowel.

**Pruritus ani.** Milder forms of this condition can usually be cured by application of the ultra-violet radiation derived from the tungsten arc. The dose usually should be: current across arc, 15 amperes; duration, 5 minutes; distance, 12 inches; focussed by a concave reflector; applied twice a week.

The more severe forms of this condition are best treated by radiotherapy.

The dose should not exceed one-third of a pastille filtered through $\frac{1}{2}$ mm. of aluminium; it may be treated once a week, or doses not exceeding one-sixth of a pastille may be given twice a week. The author's method is by means of a Coolidge tube, Bauer 6, $\frac{1}{2}$ mm. of aluminium, 2 ma. through the tube, distance 10 inches, time 3 minutes, once a week.

If both the above procedures fail to relieve this distressing condition, a cure may usually be brought about by destroying the surface of the affected parts by means of indirect diathermy, by which method the depth of destruction can be exactly regulated as required.

**Haemorrhoids.** I first reported on the treatment of haemorrhoids by diathermy in 1914, (1) and over fourteen years' experience enables me to speak highly of the permanency of the results obtained. Dr. Bordier, of Lyons,

who independently of my work started the treatment of haemorrhoids by diathermy about the same period, has published very similar results. During the past few years the method has been extensively used with good results in America.

Both internal and external haemorrhoids can be successfully treated by diathermy. The internal variety suitable for this treatment is of two types. One type is chiefly characterized by pain, and is accompanied by little or no haemorrhage: in the other type the haemorrhage is the most pronounced sign, and the pain is usually slight or absent. The treatment of these internal haemorrhoids is extremely simple, and is free from pain, the only discomfort experienced being due to the introduction of the rectal electrode. The patient lies on his left side on a large indifferent electrode, or preferably on a condenser couch, connected to one terminal of the diathermy apparatus. A cylindrical metal electrode, attached to the other terminal of the apparatus, is well oiled and introduced into the rectum. A current of from 1·5 to 2 amperes is passed for ten minutes with the patient on his left side, he is then semi-rotated on the couch, without withdrawing the rectal electrode, on to his right side, and a further period of treatment administered. A complete treatment of the lumen of the rectum is thus secured. Often one treatment is sufficient; in other cases it should be repeated daily, or on alternate days, for six treatments.

The results obtained are very satisfactory, and are attributable to the decompressor action of the heat on the neighbouring structures, thus relieving the tension, which causes the pain in the one case and the haemorrhage in the other.

When the haemorrhoids are in a more advanced stage and are prolapsed, a more severe treatment is required for their removal. The technique is as follows: The patient goes to the lavatory and forces down the piles as far as possible; he lies on a condenser couch, or on a large indifferent electrode attached to one terminal of the diathermy ap-

paratus. The protruded piles are painted with a 5 per cent. solution of cocaine, or a hypodermic injection of 1 per cent. novocain is made round the anus. This part of the technique must not be hurried, and full time must be allowed for the cocaine to take effect: the novocain should not be injected into the base of the pile, owing to the oozing of blood which would then occur and by its high conductivity would prevent the necessary concentration of the current on the part treated.

During the past few years I have entirely abandoned the use of local anaesthetic and now employ general anaesthesia obtained from nitrous oxide gas administered by an assistant. This affords ample time for the treatment, and I find that in many respects it has great advantages over local anaesthesia.

The operator holds an active electrode attached to the other terminal of the apparatus in his right hand by an insulated handle, and applies its small active surface to the pile to be treated. The apparatus being previously adjusted to yield a current not exceeding 300 ma., contact is made by the operator by means of a foot switch. The current should be slowly applied, the more slowly, within limits, the less the pain, the firmer the coagulation, and the more permanent the cure. In a few seconds the haemorrhoid will have turned an ashen-grey colour, or may even explode from the heated gases in the coagulated tissues. The current is then cut off by the foot switch and another pile treated. If the treatment is carried to the stage indicated by ashen-grey discoloration or explosion of the pile, a permanent cure will be obtained. The first patient I treated by this method, now more than eight years ago, has not had the slightest return of the trouble. The haemorrhoids in this case had existed for seven years, causing great pain and discomfort, and occasionally profuse haemorrhage, amounting, according to the patient's account, to the loss of a pint and a half of blood at a time. The patient experienced considerable pain as the immediate result of the operation, but not so

severe as to prevent her from continuing her work, as a working housekeeper, without interruption.

A considerable amount of swelling of the surrounding tissues and some pain usually follow the operation; the patient should be kept quiet, but not necessarily in bed for ten days. The amount of pain experienced varies very much, and it is very difficult to predict how severe it will be. Some cases, in which I have expected the pain to be severe, I have met out walking the next day. In other cases, where comparatively little tissue destruction has been occasioned, the pain has been so severe as to necessitate the insertion of morphia and belladonna suppositories. As a rule the pain is not great if the swollen parts can be fully returned and retained within the rectum. Hot fomentations to the perineum afford the necessary relief in the majority of cases. In only one case in my experience has there been any appreciable disturbance of the general health or a rise of temperature. This disturbance occurred in a patient liable to frequent attacks of malaria; the temperature rose on the night of the day upon which the operation was performed, and rose subsequently after each evacuation of the bowels for ten days, the temperature reaching as high as 103° F.

I have endeavoured to minimize the pain of the operation by stopping the treatment as soon as the patient said she felt the pile, upon which cocaine had previously been painted, become really hot under the electrode. But I found that cases treated only to that extent were very often not permanent. It is too subjective a method to be successful. The painlessness of the operation depends upon the care with which the cocaine is applied, and upon the slow and gradual application of the treatment. In the case of small isolated piles, especially if they are pedunculated, the pain should be slight; but large masses of piles cannot be destroyed by diathermy, or by any other means, without considerable pain and discomfort resulting from the treatment.

Sometimes the pile which is setting up acute pain is only

a very small one, not exceeding a small pea in size; in such a case indirect diathermy will effect a cure, and its application will not require either a local or a general anaesthetic: the patient will, moreover, suffer no subsequent pain and will be able to pursue his ordinary mode of life without interruption. There is, however, a tendency to produce a slight oozing of blood from the contact of the sharp pointed instrument with the acutely inflamed pile: this may be entirely obviated by inserting a very thin and small piece of mica between the point of the instrument and the surface of the pile, so getting a condenser action in place of direct contact.

The advantages of the above method are obvious: no preparation of the patient is necessary, no nursing-home is required, no general anaesthetic is needed, no confinement to bed is entailed, and the results are usually permanent. In about ten days the coagulated mass separates, leaving a healthy and granulating surface, from which a few drops of blood may ooze as the destroyed mass falls off. There is no danger of either primary or secondary haemorrhage, the deeper vessels are firmly plugged, and the superficial ones are coagulated.

### The Diseases of Nutrition

**Obesity.** The inventive genius of the eminent electrotherapist, the late Professor Bergonié, of Bordeaux, has provided us with an electrical method, based on rational and physiological principles, for the effective treatment of obesity.

Bergonié (2) describes his method as the application to the whole muscular mass of the body of an electrical excitant, specially chosen for provoking, passively and painlessly, rhythmical contractions in this mass of muscles, thereby increasing the energy expended by the physiological work and by the heat which it sets free.

The patient, when undergoing this treatment, reclines in a specially designed chair, the back and seat of which take the form of four large electrodes.

Other large electrodes are applied to the abdomen, forearms, and thighs.

These electrodes, eleven or twelve in number, covering nearly the whole skin surface of the body, are connected with eleven or twelve separate rheostats, which control the supply to each individual part, and are in turn governed by a central rheostat, which controls the supply to the body as a whole.

In very fat persons the total surface covered by electrodes is as much as 10,000 square centimetres. With such a large surface exposed, the density of the current employed is exceedingly low, amounting only to about 1/100 of a milliampere per square centimetre.

The details of the instrument have been evolved with the greatest exactitude and nicety by the inventor. For the source of supply, all the usual methods were carefully investigated; and, as the outcome of much experiment, the faradic current was finally selected. The interruptor of the coil was found to be a very important factor in obtaining painless contractions, and after long and minute researches, a trembler, giving 50 interruptions a second, emitting a musical note, always of a high and equal pitch, without pauses or variations, was obtained. The faradic coil employed is the most powerful utilized in medical electricity; it yields a current from its secondary of about 500 ma. at from 12 to 20 volts. The power absorbed in the primary, with a main supply of 110 volts, is about 60 watts (24 volts and 2·5 amperes).

In order to interrupt the secondary current, and to give the patient the necessary periods of repose, the reversing metronome has been selected as the most efficient form of instrument. It is arranged so as to give 120 beats a minute, and its double interruption, with a suitable setting of the platinum contacts which dip into mercury-containing cups, yields a double oscillation divided into four periods. 'During the first quarter of a second the muscles are at rest; they contract, excited by one of the poles, during the second quarter; they rest during the third;

contract afresh, excited by the other pole, during the final quarter.'

The selection of the brisk interruption of the metronome, in preference to the more gradual interruption by a surger, is a particularly happy one, and is in full accord with physiological principles. The sudden, brisk, quick interruption by metronome induces a form of muscular contraction, which is the counterpart of the exercises of speed (adopting Lagrange's classification of different types of muscular exercise): the slow gradual contraction, excited by the surger, is the electrical counterpart of the physiological exercises of strength.

The electrodes are kept in place during the treatment by the super-position of bags of sand. These bags serve the triple purpose of securing even co-aptation of surface, of affording an easily regulated means of increasing the work performed, and also of restraining any jerky movement of the limbs. The total weight of sand applied in this way sometimes exceeds 220 lb.

The amount of current, measured by a hot wire amperemeter, varies with the patient: a muscular patient may only require about 25 or 30 ma., whilst a really fat and oedematous patient may need as much as 70 or 80 ma. to excite efficient contraction. In no case should the current be so strong as to excite painful contractions.

The duration of the seances should be gradually increased from 20 minutes at the first application up to an hour, or even an hour and a half, when the patient has become thoroughly accustomed to the treatment. Bergonié advocates in some cases the administration of two treatments a day.

The treatments should be given about five times a week, and the course should usually consist of at least twenty treatments.

Sometimes an astonishingly rapid decrease in weight is obtained; but, personally, I am content with a reduction averaging a pound a treatment, and this amount I usually succeed in obtaining. Of course the general build of the

patient, the *dimensions énergétiques* of Bouchard (3), must be taken into consideration.

There are many ladies with whom a certain plumpness is a normal and a not unattractive condition, who, nevertheless, wish to be reduced to a slimness in accordance with the inexorable claims of fashion, which is not their normal or physiological state. To attempt such a reduction by this method is to court failure; for the method is essentially a natural or physiological one, and it is not possible by its means to reduce the weight to an abnormal extent.

As a rule in a really obese patient, a reduction of about 10 per cent. of the weight should be secured. Since, when all has been said and written, the maintenance of a normal weight, that is to say, the preservation of the mean relative to the individual, between stoutness and thinness, depends on the maintenance of the correct balance between intake and output: therefore, while we increase the output by ergotherapy, we must take care not correspondingly to increase the intake, or there will be no weight reduction. It is, therefore, necessary to limit the amount of the diet, and the more this is reduced within reason the more rapid will be the reduction in weight. It is a rather remarkable feature of the treatment that patients, who had previously failed to exist with comfort under a strictly regulated Banting diet, find but little discomfort or difficulty in considerably reducing the amount of their food whilst they are undergoing passive ergotherapy.

Bergonié has quaintly remarked that the patients to a great extent live on their own tissues, and only need a little salad to complete the dietary.

As regards the lasting effect of the treatment, this in the main depends upon the patient herself. A patient, after years of inactivity and over-eating, may have become so obese that to instruct her to take a 5 or 10-mile walk daily is an obvious absurdity. But such a patient, having lost 10 per cent. of her body weight, and her muscles having been more than proportionately developed, is placed in a position, by carefully regulated exercise, to maintain the

reduction, and the accompanying improvement in the general health: and, if she relapses for want of attention to this simple precaution, the lapse is attributable to her own fault rather than to that of the treatment.

An improvement in the general condition of the patient is usually noticeable after about the third treatment; the first thing that attracts the patient's attention is a sense of general fitness, analogous to the feeling of a well-trained athlete after a carefully regulated course of training; a feeling of lightness, or of buoyancy, as the patient sometimes describes it.

The first objective sign is usually a reduction in girth: before the scales record any marked reduction of weight, hooks and eyes in the region of the waist may need readjustment. A pathetic tale was once related to me of a lady, over 22 stone in weight, who underwent this treatment in London. She had not been able to move from her couch for several years, and so stout and flabby had she become that a nurse was engaged to move the pendulous abdomen from side to side every two hours, to prevent the occurrence of eczema intertrigo. Now this lady, after her first few treatments, actually went up in weight: but she was by no means discouraged on that account, because she had already gone down in girth.

I cannot vouch for the correctness of this story, but I quote it to illustrate a rather important point: that very fat and flabby patients may at the outset have a slight and temporary increase in weight, due to the increase in the muscular development, for it is not until the muscles are developed that they can be utilized to burn up the fats by their vigorous contractions.

One of the many advantages of passive ergotherapy by the method of Bergonié is that all the large muscles of the body are exercised simultaneously to an extent that can be regulated as a whole, or which can be readily adjusted to the requirements of each part or muscle. For example, if the abdomen is too pendulous, or too coated with fat, the treatment can be in such a case concentrated

on the abdomen, the fat burnt up, and the muscles developed and improved in tone.

'Firm and vigorous abdominal muscles form the best girdle against obesity' (Lagrange). No single athletic exercise can be regulated with the same nicety, or adjusted with the same exactitude. Let me illustrate this point from Dr. Lagrange's book (4), published in 1889, long before the method of passive ergotherapy was thought of. 'When we see fat men take to fencing in order to get thin, we notice that in them the internal fat is far from being the first to disappear; the abdomen is the region which retains with most tenacity its supply of fat. There can be nothing more awkward than the shape of a body of a man in this ungrateful period when the fat has disappeared from his arms, his chest, and his legs, while his belly remains as large as ever. The regions which have been made to work in fencing have lost their fat; the arms and legs appear slender, and the chest, which has been freed by the work of the pectoral muscles, appears shrunken by comparison with the abdomen, which has remained of its original size. It is only by continuing his exercise for some weeks still that the fat man is able to gain what he above all desires, the diminution in the size of his belly.'

Another great advantage of the Bergonié method is that it is automatic, in the sense that its operation is in no way dependent on the cerebral control of the patient. The patient is thus, as regards the exercise, placed in the position of the already skilled and trained athlete, who by constant practice has acquired an automatism of action, which, by diminishing the necessary concentration and expenditure of nervous energy, enables him to perform his exercises with far less fatigue than an unskilled and untrained person. Passive ergotherapy thus fulfils the indications which we deduce from Lagrange's law: 'The muscular work being equal, the sensation of fatigue is the more intense, the more active the intervention of the cerebral faculties demanded by the exercise.'

If any doubt remains as to the great superiority of

passive ergotherapy over all other methods for the treatment of obesity, contrast the healthy, vigorous, and athletic appearance of the patients who have undergone this treatment with the shrivelled-up look presented by the victims of a starvation diet, with their pinched countenances, their parchment skins, and their shrunken and lustreless eyes. Or compare them again with a patient who has undergone a course of drug or glandular therapy, which often owes what little efficiency it possesses to the conversion of a fat optimist into a dyspeptic pessimist.

**The Electrical Treatment of other conditions arising from Defective or Faulty Nutrition.**

The electrical treatment of these conditions we owe also to the pioneer work of Professor Bergonié. He adopts two methods of treatment, passive ergotherapy and 'La Diathermie Ration d'Appoint' (5). He sums up the action of the former by stating that passive ergotherapy should be regarded not as a form of treatment for any special disease, but rather as a therapeutic syndrome, capable of being associated with suitable drug therapy or other forms of treatment. He expresses the opinion that the treatment of such diseases as gout, chronic rheumatism, of certain cases of diabetes, of lithiasis, both biliary and hepatic, of enlarged liver, and many other conditions, should necessarily include passive ergotherapy to render their treatment rational, efficacious, and lasting.

At first sight it naturally appears irrational to apply the same remedy for the reduction of the weight of a fat person and for increasing the weight of a wasted person suffering from malnutrition. I have already quoted several times from Dr. Fernand Lagrange's excellent work on *The Physiology of Bodily Exercise*, a book, which, though published more than thirty years ago, and to a large extent lost sight of amid a multitude of recent publications of a similar kind, still remains one of the best works of reference on the subject with which it deals, and has the special merit for my purpose, that having been written so long

prior to the introduction of the methods with which we are dealing, it is free from the taunt of excessive or biased enthusiasm in relation to these forms of treatment.

Dr. Lagrange, in the following passage, shows that this double role of ergotherapy of increasing or decreasing the weight is in no way inconsistent with the physiology of muscular exercise. 'We have seen that work has two opposite influences on nutrition: it increases the gains, and it also increases the losses of the system. The hygiene of work essentially consists in balancing these two opposed results; but certain conditions of exercise may make now one, now the other, predominate, and it is possible to obtain almost at will, by the aid of muscular work, either an increase or a diminution in the weight of the body.'

The argument in support of the *diathermie ration d'appoint*, or the supplementary ration of diathermy, is that in a number of marasmic conditions there is an inability to take or assimilate the nourishment necessary both for the maintenance of the heat and the nourishment of the tissues of the body: and that to overfeed such cases only makes matters worse, for the weakened digestive system rebels against the overfeeding, and indigestion is then added to the pre-existing troubles. On the other hand, by transfusing heat through the tissues by means of diathermy, that portion of the food which would be otherwise burnt up in the maintenance of the body temperature is diverted to the nourishment of the body, and so helps to establish the normal equilibrium between intake and output. 'It is a fortunate occurrence,' remarks Professor Bergonié, 'by no means a rare one in physiotherapy, that the more grave the condition is, the more efficacious the remedy becomes' (5).

The method of application of this treatment is by means of large electrodes covering in all a superficial area of from 1,000 to 3,000 square centimetres. They are applied in the following manner: one on each side of each upper arm, one on the inner and outer side of each thigh, and one on the inner and outer side of each leg, twelve electrodes in all.

They are secured in position by rubber bandages. The electrodes on one side of the body are connected with one terminal of a diathermy apparatus, those on the other side with the other terminal. An intensity of current of from 1 to 2·3 amperes is administered for about 40 minutes. With these large electrodes and this intensity of current, the current density only amounts to about 1 ma. per square centimetre, and is consequently so far within the limit of safety that the intensity of the current may be safely increased, if it is desired to do so.

In the case of a typical application quoted by Bergonié, the following formula represents the intensity of current applied:

$$\frac{2{\cdot}3 \text{ amperes}}{1200 \text{ cm.}} = 0{\cdot}00191 \text{ ampere.}$$

To obtain satisfactory results from this treatment, and also from ergotherapy, whether applied for obesity or malnutrition, it is essential that its administration should be under the constant observation and direct control of a medical man. The indications for variations in the degree, in the location, in the character of the treatment so frequently arise, that it is impossible to issue general instructions to a nurse or masseuse which will meet all the requirements of the case during the course of treatment.

The general indication for the supplementary diathermy ration occurs whenever it is desirable to raise the temperature of the body as a whole. In fact, this form of treatment is nothing more than the application to the body as a whole, and to general and constitutional diseases, of that form of treatment which electrotherapists have found so beneficial in the treatment of local diseases and lesions.

Bergonié points out as special indications the marasmic diseases of children, athrepsia induced by neoplasms, malnutrition associated with stricture of the oesophagus or cancer of the stomach or liver, and the hypothermia following profuse haemorrhage.

The most noticeable physical result recorded by Ber-

gonié as the result of experiments is a rise of the temperature in the axilla of 2·1° C. in 16 minutes with a current intensity of 1·7 ampere, whilst the rectal temperature was only raised 0·1° C. The blood pressure was raised from 15 to 19 cm. of mercury. A definite lowering of the respiratory exchanges occurred:

Respiration during ten minutes.

| Before diathermy. | After diathermy. |
|---|---|
| 2·95 litres oxygen consumed | 2·14 litres |
| 2·62 litres of $CO_2$ output | 1·96 litres |

Bergonié concludes that we have in diathermy the most rational and active means of assisting the organism, when in a state of physiological misery, whatever may be the cause of this condition; for we are able to bring to it, in the natural form of heat, a supplementary ration which compensates for its deficient energy, without making any call upon the digestive system.

Dr. Oliver Wendell Holmes appears to have in some degree anticipated Bergonié's idea of the 'Ration d'Appoint':

When the charge galvanic tingled through the cable,
At the polar focus of the wire electric
Suddenly appeared a white-faced man among us:
    Called himself 'De Sauty'.

As the small opossum held in pouch maternal
Grasps the nutrient organ whence the term mammalia,
So the unknown stranger held the wire electric,
    Sucking in the current.

When the current strengthened, bloomed the pale-faced stranger,
Took no drink nor victual, yet grew fat and rosy,
And, from time to time, in sharp articulation,
    Said 'All right! De Sauty'.

OLIVER WENDELL HOLMES.

*The Professor at the Breakfast Table.*

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# CHAPTER V

## THE GENITO-URINARY SYSTEM

### In the Male

**Incontinence of urine.** If, after obvious causes, such as phimosis, calculus, &c., have been removed, and suitable methods of training and discipline have been given a sufficient trial, the trouble still persists, electrical treatment of this troublesome condition offers sufficient prospect of improving or curing the condition to warrant its adoption.

In children, the usual method is to apply the faradic current from a coil with a coarsely wound secondary. One pad is placed over the lumbar region and the other on the perineum. The treatment is given daily for about ten minutes of a strength permitted by the toleration of the patient.

In the treatment of the incontinence of urine in adults, I have obtained the best results from the use of the unidirectional discharges of high voltage obtained from the so-called Morton Induced Currents of the static machine.

A rectal electrode is introduced and connected with the Leyden jar, the outer coating of which is negatively charged; a pad is secured just above the pubes, or to the perineum, and is connected with the outer coating of the other jar, which has a positive charge. The discharging balls of the static machine are gently opened and closed, or the author's automatic static surger is employed, so as to give a surging character to the current. Each treatment has a duration of about fifteen minutes. The explanation of the action of this treatment naturally depends on the view we take of the pathology of the condition.

If the trouble is due to an atony of the sphincter of the bladder, then the beneficial effects of the treatment would be attributed to its action in the strengthening

of the sphincter. If, as is more generally held to be the case, it is due to faulty cerebral control, the improvement resulting from the treatment would be regarded as the outcome of a reflex stimulation and a strengthening of such control.

**Urethral calculi.** The primary action of the diathermy current in developing heat in any organ however deeply situated, and the secondary effect of this heat in inducing relaxation of spasm, suggests the employment of diathermy to relieve renal colic, and also by relaxing the spasm, set up by the presence of the calculus, to facilitate its passage through the ureter.

As the result of an error of diagnosis, I on one occasion applied diathermy for a dull aching pain in the back, occasioned by a calculus gripped in the ureter. Considering the pain to be due to lumbago, I applied diathermy transversely through the back; the pain was at once relieved, but on returning home the patient was about twenty minutes later seized with the agonizing pain of renal colic, and in due course passed a stone.

**Gonorrhoea.** Electrical treatment may be applied with success to the early or later stages of this disease; but those who have had much experience of general practice will know that the majority of these cases can be more simply cured by urethral injections, such as mercurol, aided by suitable medicines. Occasionally, however, old-standing and intractable cases arise, which are not so easily dealt with; and these can usually be cured by an electrical method first described by Bouchet, in the *Journal des Praticiens*, February 9, 1907 (1).

Tousey, in his book, *Medical Electricity*, thus describes Bouchet's method: 'A soft rubber catheter with multiple eyelets is used to irrigate the urethra with some solution, such as 1 to 2 per cent. solution of sulphate of zinc, which forms the positive electrode for a current of from 1 to 10 ma. Bouchet makes the electric connexion with the liquid by the use of a fine platinum wire, which passes through almost the entire length of the catheter, and which

is fastened to a metal tubé inserted between the tube from the irrigator bag and the catheter. It is to this metal tube that the positive wire is secured. The other electrode is applied to any other indifferent region. An irrigation with two quarts of solution is enough for each application. In acute cases, where the treatment is begun on the first or second day of the disease, Bouchet has found that daily treatments cause immediate disappearance of the discharge and sterilize the urethra of gonococci in fourteen days. In thirty chronic cases he obtained a complete cure in three or four weeks by applications made every other day.'

The therapeutic action here is, of course, identical with that which occurs in the electrolytic treatment of septic sinuses, endometritis, mucous colitis, &c., and is clearly due to the stimulating or caustic action, varying with the nature of the solution employed and the strength of the current, of the nascent products of the electrolysis on the neighbouring tissues.

Orchitis, epididymitis, and neuritis of the testicle are much relieved by diathermy. The active electrode usually recommended in the treatment of these conditions is a rather complicated one composed of metal: with this instrument it is difficult to secure good contact. The simplest and most efficient technique is to utilize a 10 ounce conical glass measure, in the bottom of which a small lead weight is placed, and is attached to the active rheophore. The glass vessel is nearly filled with salt solution, and the testicles are placed within it. The indifferent electrode is formed by a moist pad and plate upon which the patient sits. In this way perfect contact and an efficient line of force, including the testicle, epididymis, vas and prostate are secured.

**Impotence.** Of the treatment of this condition by electricity I have no experience. Nogier (2) sums up the results obtained as follows: 'In certain cases the cure is fairly rapid, in others it requires as many as twenty-five or thirty treatments to obtain the desired

result.' I should imagine that for a very large number of cases even thirty or sixty treatments would be insufficient.

One case of severe neurasthenia, associated with the fear of impotence, that I treated by the method described for the treatment of orchitis was apparently cured.

Ulcerations of the penis, such as soft chancres, usually yield readily to ultra-violet radiation. Such treatment should, of course, be combined with the usual syphilitic remedies.

**Diseases of the Prostate.** The Morton wave current has been much extolled as a remedy for enlargement of the prostate. In few conditions is an accurate diagnosis of greater importance, or more difficult to obtain, before the commencement of treatment than in enlargement of the prostate. It is perfectly obvious that the Morton wave current is entirely unsuited for malignant disease, and yet the exclusion from the diagnosis of malignancy in prostatic enlargement often baffles the most skilled urologists. The Morton wave current cannot benefit a calcareous or even a fibrous prostate beyond assisting to massage away a co-existent or secondary oedema, which may be aggravating the condition. An oedematous or congested prostate, on the other hand, or a prostate in whose acini chronic suppuration is proceeding, may be immensely benefited by the Morton wave current. I have had many failures in the treatment of enlarged prostates owing to this difficulty of ascertaining the primary cause of the enlargement.

The action of the Morton wave current on the prostate is wholly and solely one of massage; it is, however, not only the most effective form of prostatic massage, but it is the only really effective form.

As the result of the patient's electrical discharge through his prostate, the whole gland vigorously contracts, and so squeezes out any oedema or other fluid accumulation. The periods of contraction alternate with periods of rest.

Owing to the high voltagé employed, the whole gland is permeated by the current and contracts as a whole as the discharge takes place. These vigorous contractions, so excited, alternating with periods of rest 120 times a minute, exercise a type of muscular auto-massage, compared with which the ordinary forms of prostatic massage are most inefficient and ineffective.

The application of the treatment is painless, it is the cleanest and the least objectionable form of prostatic massage. The patient is given a rectal electrode, with an olivary metal terminal projecting at right angles from an insulating vulcanite base. The patient himself usually introduces the electrode, keeps it in place by sitting on the insulated stem, through which runs a wire connected with the positive pole of the static machine. The rods of the apparatus are separated to an extent well within the toleration of the patient, and the treatment is thus administered for about fifteen minutes.

Occasionally we meet with cases of prostate obstruction which yield most readily to this treatment. Such a case was the following: a clergyman, of about sixty years of age, was sent to me for electrical treatment of an enlarged prostate, which occasioned such frequent micturition that he was unable to preach or to lecture. A short course of the Morton wave current completely cured this patient, and he remained free from any trouble of the kind for six or seven years. He then had a slight relapse which readily yielded to a repetition of the treatment, and since then he has not suffered from any more trouble of the same nature.

In cases of old-standing gonorrhoea, it is often necessary thoroughly to drain the crypts, follicles, or acini of the prostate from accumulations which may be the residual cause of the trouble. For such conditions the Morton wave current is the ideal treatment.

Painful and inflammatory conditions of the prostate can usually be relieved or cured by diathermy applied by means of a metal electrode in the rectum and an

abdominal pad. The current should only be sufficient to produce a feeling of warmth. Adhesions within or around the prostate may be broken down by the Morton wave current.

In the ordinary senile adenomatous enlargement of the prostate, small and spaced doses of X-rays, one-sixth of a pastille twice a week, or one-third of a pastille once a week, filtered through 2 or 3 mm. of aluminium, hold out the best prospect of relief of any electrical methods: but I have found it advantageous in some cases to combine the radiotherapy with alternate treatments by the Morton Wave current.

The X-rays can be conveniently administered in these cases through the seat of a stool or chair, upon which the patient sits and under which the X-ray tube is placed, the rays passing through a central hole cut in the seat of the chair.

### In the Female

**Endometritis.** In no disease is the value of electrical treatment more clearly demonstrated than in endometritis. It was from the success which I obtained, when in general practice, from the electrical treatment of endometritis, that I was first convinced of the very great value of electricity as a curative agent. I then found that cases of endometritis with suppurative discharge, which had undergone months and years of irrigation without benefit, were usually cured by one to three treatments of intra-uterine electrolysis. In two instances married women, who had been sterile for five or more years in consequence of a purulent discharge, and who became pregnant after their endometritis had been cured by electrolysis, reproached me for not warning them that as the result of the electrical treatment they would again become capable of conception.

The electrical treatment of endometritis is so simple, so safe, so successful, and so painless that its general

adoption in place of curetting can only be accounted for on the ground that it is so little known.

Contrast the nature of this treatment with that of curetting.

In electrolysis no previous preparation of the patient is needed, a zinc or copper electrode is introduced within the uterine cavity with no more pain or discomfort than attends the introduction of a uterine sound for diagnostic purposes, the strength of the electrical current is immediately reduced if it causes any pain; after about fifteen minutes' treatment the patient is able to walk or drive home—no nursing-home is required. The action of the electrolytic products automatically extends and permeates to every part of the lining of the uterus, to every crypt and follicle of the mucous membrane. The electrolytic products have an antiseptic action, and their cauterizing effect is readily controlled by the duration of the treatment and the intensity of the current, and the latter cannot be excessive if it is not pushed beyond the easy toleration of the patient.

Curetting, on the other hand, usually necessitates the inconvenience and expense of a stay in a nursing-home, it entails the risks inseparable from the administration of an anaesthetic, the possibility of subsequent trouble resulting from the forcible dilatation of the os uteri, the operation is of necessity blindly and perfunctorily performed, a raw surface is laid open for septic invasion, and there is no guarantee that the most diseased portion of the mucous membrane has been reached by the curette. In cases where there are placental remains to be removed, curetting is the more effective operation; but in uncomplicated cases the good results from electrolysis are far more certain and constant than those from curetting. Examination of the curetted portion of the mucous membrane is often of value; but electrolysis often affords equally valuable information of another kind. For, if with the electrical method acute pain on one or other side of the uterus accompanies the application of a current of moderate

strength, it may be safely concluded that the tubes or ovaries on that side are affected; in such cases the electrical treatment should immediately be discontinued, and the case should be sent to a surgeon.

The technique of the treatment is important. The patient's abdomen is enveloped in bath towelling soaked in salt solution, and the metal electrode should extend completely round this pad, so as to ensure an even distribution of the current within the uterus; this pad is connected with the negative pole of the source of supply. A zinc or copper uterine sound is attached by a rheophore to the positive pole of the battery, and is carefully introduced within the uterus. In cases where there is a septic discharge, it is customary to recommend the choice of a zinc active electrode, on account of the special antiseptic properties attributed to the action of the oxychloride of zinc; where haemorrhage is a prominent symptom, the copper electrode should be chosen, on account of the styptic properties of the copper salts. The vaginal or extra-uterine portion of the electrode should be insulated by means of a piece of rubber tubing or a portion of an unused gum-elastic catheter. Where there is ulceration of the os uteri, as is commonly the case where the disease is of old standing, this condition may be treated simultaneously with the interior of the uterus, by wrapping a pledget of wool or lint, soaked in a 2 per cent. solution of sulphate of zinc, round the stem of the electrode, and pushing it against the os uteri by means of the insulating vaginal tube. The patient is placed in the Marion Sims position, and, the electrodes being in position, a galvanic current is very gradually applied up to an intensity of 20 to 30 ma. for a period of fifteen to twenty minutes.

The strength of the current should be immediately reduced if it occasions pain. Occasionally towards the end of the treatment some discomfort may arise from the excitation of uterine contractions; if it persists after the completion of the treatment, it may be readily removed by

diathermy or the application of the leucodescent lamp. The risks of the treatment would appear to be merely those of the introduction of a uterine sound.

The researches of Dr. Cumberbatch and Dr. Robinson on the treatment by diathermy of gonorrhoea and other genito-urinary diseases have been carried out with a careful attention to detail that has but rarely been devoted to the solution of problems connected with electrotherapy. The work of these investigators has yielded most valuable results and they have evolved a technique which raises the treatment of these conditions to a speciality of its own. One of the most valuable and far-reaching conclusions which these co-workers have deduced from their investigations is that, in the treatment of the infection of the cervix by organisms other than those of gonorrhoea, namely such organisms as 'coliform bacilli, diphtheroid bacilli, and the streptococcus faecalis', cure or arrest of metastatic arthritis or fibrositis have resulted from application of diathermy to the cervix.

**Dysmenorrhoea, Menorrhagia, and Amenorrhoea.** My attention was first directed to the very valuable relief obtainable from diathermy in cases of painful menstruation by a patient whom I had been treating for abdominal pain, assumed to be due to a floating kidney, saying to me, 'Do you know that since my last treatment I had the first menstrual period, free from pain, that I have had for 17 years?' Acting on this accidental hint, I found that five out of six cases of severe menstrual pain derived very great benefit from diathermy; a result that a realization of the action of diathermy and the spasmodic nature of menstrual pain would naturally lead one to expect. The treatment is applied by a large indifferent electrode over the back, and an active electrode over each ovarian region in turn. The pads should be about 20 × 10 cm. in size, and the current should be approximately two amperes for ten minutes over each area. The treatment is given daily for the three days preceding an expected period, and is usually discontinued during the period; but if the pain recurs, the

treatment should be administered during the period. The effect of the treatment is occasionally to bring on the period before the expected time.

Menorrhagia, occurring about the time of the menopause, is best treated by radiotherapy. Menorrhagia occurring in young married women can, after the possibility of pregnancy has been with certainty excluded, be satisfactorily treated by intra-uterine electrolysis by means of a copper electrode.

Amenorrhoea, for which no obvious cause can be found, can frequently be remedied by diathermy. The treatment is applied in very much the same manner as for dysmenorrhoea; but the current should be of lower intensity, and applied for at least half an hour. It should be applied for about six days before the period is calculated to be due. Menstruation has been regularly established in the few cases which I have treated in this manner. The action of the treatment is clearly due to the increased functional activity of the ovaries, resulting from the increased blood supply induced by the administration of the heating current.

Some 'neuralgic' pains in the ovarian region, and also some pains attributable to peritoneal adhesions, can be relieved by diathermy.

**Sterility.** The treatment of this condition obviously depends upon its cause. If the sterility is regarded as in any way due to spasmodic dysmenorrhoea, a condition commonly associated with sterility, then a trial should certainly be made of diathermy applied to the ovarian region. Where sterility is due to a diseased condition of the endometrium, no method holds out better prospects of success than the electrolytic treatment of endometritis. In an earlier chapter a case of recurrent abortion is recorded, in which a full-term child was born in due course after treatment by electrolysis, after frequent curetting and various other measures had been previously tried without success.

**The Climacteric. Metrorrhagia. Uterine Fibroids.** In his

book *Diathermy, its production and uses in Medicine and Surgery*, Dr. Cumberbatch writes as follows in reference to metrorrhagia: 'The metrorrhagia which sometimes occurs during the climacteric responds admirably to pelvic diathermy. Speaking from the experience gained in the Electrical Department of St. Bartholomew's Hospital, the treatment is always successful. Even if there are severe floodings the bleeding is quickly stopped. In some cases there may be one or two more normal periods before permanent cessation of menstruation. In others there is no return of menstruation or bleeding after the metrorrhagia has been terminated by diathermy.' These are remarkably good results to obtain in such a serious and troublesome condition, and in a condition which is so very resistant to the ordinary methods of treatment. An extended trial of this method is certainly called for.

Uterine fibroids are best treated by the radiation of the uterus and ovaries with X-rays.

One of the most exhaustive and instructive papers on the radiotherapy of uterine fibroids is that by Dr. Béclère (3), entitled 'La Radiothérapie des Fibromyomes utérins, Résultats, Mode d'Action et Indications d'après une Statistique de 400 Observations personnelles', communicated to the Brussels Congress of the 'Association des Gynécologues et Obstétriciens de Langue française', September 27, 1919.

In the method advocated by Dr. Béclère the treatments were of moderate strength and were administered weekly. The penetration was of the value of a spark gap 15 to 20 cm. Filtration, 5 mm. aluminium. Distance, tube 18 to 22 cm. from surface radiated. Duration, each radiation 5 minutes. An application to each ovarian region at each seance. Intensity, 2 ma. through tube. Pastille measurement, after traversing filter, 3 to $3\frac{1}{2}$ H.

Of the 400 cases upon which Dr. Béclère's observations were based, 24·5 per cent. of the patients were 50 years of age or more; 64 per cent. were from 40 to 49; 11·5 per cent. were from 30 to 39.

15·5 per cent. of the tumours were within the limits of the pelvis. 84·5 per cent. extended into the abdominal cavity.

The following were the number of treatments required:

| | | | |
|---|---|---|---|
| 4 to 11 | treatments in | 38 | patients |
| 12 ,, 14 | ,, | ,, 202 | ,, |
| 15 ,, 20 | ,, | ,, 109 | ,, |
| 21 ,, 30 | ,, | ,, 45 | ,, |
| 31 ,, 50 | ,, | ,, 6 | ,, |

The most noticeable results obtained were the suppression of the periods and the diminution in the size of the tumours. In four cases only of the 400 was surgical interference called for—it was in those cases required on account of the profuseness of the haemorrhage. With his more recent and perfected technique, Dr. Béclère thinks that even this small number might be reduced.

The periods ceased as in the following table:

| | | | |
|---|---|---|---|
| Without any reappearance of the periods | | in | 3 patients |
| After 1 appearance | | ,, | 61 ,, |
| ,, 2 appearances | | ,, | 128 ,, |
| ,, 3 ,, | | ,, | 89 ,, |
| ,, 4 ,, | | ,, | 29 ,, |
| ,, 5 ,, | | ,, | 9 ,, |
| ,, 6 ,, | | ,, | 8 ,, |
| ,, 7 ,, | | ,, | 3 ,, |
| ,, 8 ,, | | ,, | 4 ,, |
| ,, 10 ,, | | ,, | 2 ,, |

The diminution in the size of the tumours is shown in the following table:

| | | | |
|---|---|---|---|
| From 1 to 2 | centimetres | in | 12 patients |
| ,, 3 ,, 4 | ,, | ,, | 42 ,, |
| ,, 5 ,, 6 | ,, | ,, | 73 ,, |
| ,, 7 ,, 8 | ,, | ,, | 62 ,, |
| ,, 9 ,, 10 | ,, | ,, | 52 ,, |
| ,, 11 ,, 12 | ,, | ,, | 26 ,, |
| ,, 13 ,, 14 | ,, | ,, | 10 ,, |
| ,, 16 | ,, | ,, | 1 patient |

Dr. Béclère concludes that, with the exception of those cases that imperatively call for surgical interference, all types of uterine fibromata are suitable for radiotherapy.

In view of the work of Regaud, which so clearly proves

that certain cells, and especially cells of such functional activity as characterizes the cells of the ovaries, vary greatly in respect of their radio-sensibility[1] at different stages of their existence, it would be a very strong argument in favour of the divided doses of Béclère's method, if this period of maximum radio-sensibility was reached by different ovarian cells at different times. The work of Wintz, however, tends to show that this is not the case, but that the period of maximum radio-sensibility of the ovarian cells occurs simultaneously in the different ovarian cells during the first fortnight following the menstrual period.

It is of interest to contrast the method of Béclère, which may be regarded as representing the best technique for the divided dose method, with the application of a single sterilization dose advocated by Dr. Wintz, of Erlangen.

In the method of Dr. Wintz, a mean depth from the skin, after compression has been applied, is assumed for the surface depth of the ovaries. A calculation is made by very precise technique of the amount of radiation which the ovaries will receive at this assumed depth.

Assigning a value of 100 to the skin erythema dose, the dose necessary for the sterilization of the ovaries is stated to be 34 (34 per cent.).

Very heavy filtration by 0·5 mm. of zinc is employed. The 'self-hardening water boiling tube' (for convenience termed the 'Wintz tube') is previously calibrated by means of a standard tube, and by aid of tests with the iontoquantimeter; the only measurement of the dose employed in the actual working in the treatment room is one of time.

[1] It will materially assist the comprehension of the phenomenon of radio-sensibility if it is clearly realized that the expression 'the selective action of X-rays', so often applied, is a very incorrect and misleading one: the so-called selective action is not an attribute of the X-rays, but is the result of the varying sensibility of the cells at different periods of their cycle to X-rays or the gamma rays of radium.

For the correct administration of this time measurement, Wintz points out that the following factors are essential:

The dose produced by the X-ray tube per unit of time must be known.

The penetrating power of the rays necessary for the treatment must be known.

Tubes must be employed whose dose per unit of time remains constant, and also the penetrating power of the rays produced must remain constant (other conditions remaining the same).

X-ray apparatus must be employed of which the output is constant.

Measuring instruments of the required accuracy must be used to show the current passing through the tube, and also the E.M.F. which is applied to the terminals of the tube.

Using a port of entry $6 \times 8$ cm. the erythema dose is obtained, under certain conditions of tube and current, in the following times at the various focal-skin distances:

| | | | | | |
|---|---|---|---|---|---|
| At 23 centimetres | focal-skin | distance | in | 35 | minutes |
| At 30 | ,, | ,, | ,, | 59 | ,, |
| At 50 | ,, | ,, | ,, | 165 | ,, |

Wintz strongly advocates the administration of a sterilization dose at a single treatment, lasting for 2 to $2\frac{1}{2}$ hours, applied within a fortnight of a menstrual period. After such a treatment he states that a recurrence of haemorrhage will be prevented. But if the irradiation is administered in the fortnight preceding the occurrence of the menstrual period, one or more haemorrhages may occur. This observation is of great importance as indicating the period of maximum sensibility of the ovaries.

If a 'complete sterilization dose' has already been administered, it is not safe to repeat it in the event of recurrence of the periods.

If a complete sterilization dose is given at one treatment in the first fortnight following a menstrual period, no

further haemorrhage occurs in 95 per cent. of cases. If the dose is divided into several sittings, haemorrhage completely ceases in 93 per cent. If the dose is given in one treatment in the second fortnight after the period, one further haemorrhage occurs in 80 per cent.; and if the treatment is given at a corresponding time, and in divided doses, two further periods will occur in 84·4 per cent.

Wintz, though he is so strong an advocate of the single dose, admits that in nervous patients its administration is impossible, and in such cases he recommends its division into two applications.

This method of sterilization is not usually applied in cases of simple menorrhagia before the age of 40 has been reached; its chief use lies in the haemorrhage preceding the menopause.

Wintz regards the presence of a sarcoma as no contra-indication to the treatment; on the contrary, he states that in such cases the results of irradiation are far superior to those of surgical operation.

In the last three and a half years Wintz claims to have carried out 500 sterilizations without a single failure. The same sterilization dose is administered for both young and old patients.

'In 7,000 cases which we have treated, there are only two in which at a later date, sometime after the irradiation, damage to the skin occurred.'

Increased experience of the two methods leads to the conclusion that for the induction of the menopause the divided dose of Béclère is to be preferred to the single dose of Wintz: this preference is based largely on the fact that in the after-history of the cases treated by the two methods, those which have undergone the divided dose exhibit no lasting constitutional symptoms: whereas those cases, in which the periods have been suddenly interrupted by the single massive dose, often exhibit constitutional and mental symptoms persisting for months or years.

The various troubles associated with the climacteric form a very large proportion of the ailments which occur in

middle-aged females. These unfortunate women, month after month, often for several years, consume vast quantities of potassium bromide, nux vomica, and similar drugs with only temporary relief to their sufferings. Though their health during these years is such as to render their life a burden to them and to incapacitate them to a large extent for their household and other duties, yet the symptoms are usually of insufficient severity to bring them into the hands of the gynaecologist or X-ray specialist.

In such cases the massive X-ray dose is not required, but the small spaced dose, in accordance with Béclère's method, brings about, after an average of eight treatments, a lasting and complete relief from their troubles. The need for and the beneficial effects of such treatment are not sufficiently recognized by the medical profession.

Though radiotherapy for cancer is by no means confined to the treatment of this disease when occurring in women, nevertheless it has been hitherto employed in this class of the disease to such a preponderating extent that this chapter affords the most convenient opportunity for discussing its action.

Up to the present time it must be frankly confessed that radiotherapy has not yielded very encouraging results in the treatment of cancer. The work of Dr. Wintz and his school, however, sheds so much fresh light upon this subject that his illuminating book should be read by all those specially interested in the treatment of cancer.

Wintz finds that the necessary dose to destroy cancer cells is 110 per cent. of the sterilization dose ; their radiosensibility, therefore, is not greater than that of the skin. The difficulty of treating epidermal cancer is thus obvious, for it is of course impossible to treat it through more than one port of entry. The upper layer of cancer cells may be destroyed, but the underlying cells will receive an insufficient dose. Wintz, however, points out that if the cancer growth is situated about 3 cm. from the surface it can be successfully treated by employing a focal distance of 100 cm.

Where there is general metastasis, the cumulative action of the X-rays needed to destroy the individual deposits is greater than the body (the white corpuscles) can tolerate, therefore such cases cannot be successfully treated by radiotherapy.

In the treatment of uterine cancer, Wintz employs six ports of entry, necessitating a duration of treatment from 4 to $4\frac{1}{2}$ hours. Morphia is hypodermically administered so that the patient may sleep through the greater part of irradiation. The after-effects vary considerably; some patients vomit during the treatment and this vomiting may continue the next day.

Sometimes diarrhoea occurs, and the patient may not recover from these and other after-effects for from eight to fourteen days.

Wintz emphasizes the importance of not spreading the dose over several sittings. A few patients do not recover from the action of the irradiation on the blood, and die in about the same time that they would have done if the growth had remained untreated. Wintz gives a latitude of 20 per cent. between which the success or failure of the treatment depends. There is a danger of severely injuring the intestines if too large a dose is given—it should consequently under no circumstances exceed 130 per cent.

Wintz expresses the opinion that, in future, uterine carcinomata should be irradiated, and not operated upon, but surgical extirpation has certainly not at present been in any way superseded by any form of radiation.

The Wintz method does little or nothing to realize the hopes which many have entertained that in radiotherapy we might find a cure for disseminated and inoperable cases of cancer. The only hope of achieving a result, so much to be desired, would seem to lie, not in the use of more powerful apparatus, the limit of which appears to have been reached in the Wintz instrumentation, but in the discovery of some method by which the radio-sensibility of the cancer cells can be increased.

The most recent trend of advance in radiotherapy ap-

pears to be along the line of the repeated and spaced application of small doses and to a decreasing employment of the massive dose.[1]

**Pruritus vulvae.** The electrical treatment of this condition is identical with that of pruritus ani which has already been described.

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2. Nogier, *Électrothérapie*, 1907.
3. Béclère, 'La Radiothérapie des Fibromyomes utérins', *Journal de Radiologie et d'Électrologie*, July 1919.

[1] Béclère, in an appreciative criticism of the work of Seitz and Wintz, concludes that the divided dose method of moderate intensity is still to be preferred to the single dose intensive method: because the former does not produce any constitutional disturbance calculated to interfere in any way with the patient's mode of life or with her occupation, the result is obtained with a minimum of radiation, and it is the only method suitable for large tumours. Béclère, however, proposes in the future to employ a more penetrating radiation than he has hitherto used.—Béclère, 'Sur la rœntgenthérapie des fibro-myomes utérins', *Journal de Radiologie et d'Électrologie*, October 1921.

# CHAPTER VI

## DISEASES OF THE BLOOD, AND THE GLANDS

THE action of the radiation from X-ray tubes and from radium upon the blood is of very great importance, both on account of its beneficial or therapeutic action in leukaemia, and its malignant or morbid action on the workers constantly exposed to the radiation.

A most instructive and exhaustive paper on the action of X-rays on the blood, entitled 'De l'Action des Rayons X dans la Leucémie', by MM. A. David et R. Desplats, (1) appeared in the *Archives d'Électricité Médicale*, May 25, 1912. This paper not only expounds very fully and clearly the ideas of the authors, but also fairly and critically examines the views propounded by other writers, and concludes with a bibliography of the subject, including thirty-seven references. It should be read in its entirety by all those specially interested in this subject. The following comments and extracts will give an idea of the scope of the thesis.

David and Desplats commence by quoting the various theories which have been propounded to explain the action of X-rays on the blood.

1. **The microbic action of X-rays.** Senn (2) attempted to explain the action of X-rays in leukaemia by their destructive action on hypothetical microbes, which at one time were thought to be the cause of the disease. The microbic origin of the disease is now practically abandoned, and the amount of radiation employed in this treatment would probably be insufficient to account for their destruction if they were present in the blood.

2. **The action of the X-rays on the haematopoietic organs.** Heinecke (3) has demonstrated the great radiosensibility of lymphatic tissue: but though the tissue may appear to be completely disorganized by the radiation, nevertheless, in 8 to 14 days, complete regeneration of the follicles may have occurred.

This marked radio-sensibility belongs to the lymphoid tissue; the pulp of the spleen and the bone marrow is not by any means so radio-sensitive.

David and Desplats arrive at the conclusion that 'though the destruction of the lymphocytes may be explained by the destruction of the lymphoid tissue, the destruction of the myelocytes may not admit of an analogous interpretation'.

3. **The action of the X-rays on the blood in circulation.** Aubertin and Beaujard (4) were the first to study contemporaneously the effect of radiation on the blood in circulation, and on the haematopoietic organs. This they accomplished by administering doses of therapeutic strength to the whole bodies of small animals.

The first thing noticed was a leucocytosis due to an increase of the polynuclears. This phase was of such a fleeting character that, unless the blood was carefully and systematically examined soon after the irradiation, it escaped notice. It might even disappear as early as three hours after the exposure. A similar fleeting occurrence of polynuclear leucocytosis can be noticed in cases of myeloid leukaemia soon after the irradiation of the bone marrow.

This leucocytosis occurs too soon after an irradiation to allow of the formation of fresh leucocytes. It is probably an exodus of polynuclears from the bone marrow, where they are kept in reserve pending a sudden call for their services, in the same way that a fire engine is held in reserve for emergencies at a fire station (Ehrlich).

In the same way Aubertin and Beaujard regard this as an emigration under the influence of the X-rays of the polynuclears from the myelogenic organs; and they believe it to be an emigration which is not peculiar to the polynuclears of the myelogenic organs, but that it is one which will be found in the lymphocytes from the lymphogenic organs.

Post-mortem examinations of guinea-pigs, killed two to four hours after exposure, demonstrated that the spleen

did not present any signs of injury; and that the marrow of the bones was in full activity, macroscopically more red, and microscopically more congested, with fewer polynuclears.

The leucocytosis was succeeded in the irradiated guinea-pigs in about 24 to 36 hours by a marked leucopenia; at that time, however, there was a percentage predominance of polynuclears, in spite of an actual diminution in their count. This is attributed to the greater vulnerability of the mononuclear elements to the X-rays, and also in part to the specimens having been prepared from dried blood. The phase of immigration is thus succeeded by one of destruction in the case of the irradiated guinea-pig, and similar evidence of destruction is found in cases of leukaemia after they have been exposed to X-rays.

As regards the red corpuscles a slight but constant diminution in their number followed the irradiation of the guinea-pigs.

Aubertin and Beaujard point out that the leucopenia cannot be due to a hypo-functioning of the lymphoid tissue, because the lesions of the lymphoid tissue are fully restored after 48 hours. It cannot be due to medullary insufficiency, because it occurs in spite of a marked medullary hyper-activity, which is more marked as the leucocytic count is below the primitive count.

They conclude that this leucopenia, in the conditions under which they have observed it, results from a direct or indirect destruction (by the intermediary action of leucolysins) of the leucocytes in the whole organism, and this can occur without medullary degeneration, for in spite of marked medullary hyperplasia the destruction exceeds the formation.

David and Desplats conclude from these experiments of Aubertin and Beaujard that leucopenia, in the conditions in which it is observed after radiotherapy, cannot be attributed to a destruction of the lymphoid or myeloid tissue.

4. **The leucolysins.** The leucolysin theory explains the

therapeutic action of X-rays in leukaemia by the formation, as the result of the radiation, of substances in the blood capable of destroying the white corpuscles.

Helber and Linser (5) held that the action of X-rays was due to a destruction of the lymphocytes circulating in the blood, and that the changes in the haematopoietic organs were due to the action of leucotoxins thus set free.

Various substances, such as a biochemical modification of lecithin (Werner (6)), have been suggested as capable of formation in this way, and capable of effecting the results stated.

Curshmann and Gaupp (7) went farther, and produced experimental evidence in support of the theory. 'Struck by the fall in the number of leucocytes provoked by an irradiation in a case of lymphatic leukaemia, they injected under the skin and into the veins of rabbits the serum of leukaemic patients who had undergone irradiation. They found that a considerable diminution in the number of the white corpuscles occurred, the minimum being reached in $4\frac{1}{2}$ hours after the injection. If the leukaemic serum was rendered inactive by heating to 60° C. for half an hour, the leucocytic fall is scarcely shown, and is, moreover, at its lowest an hour and a half after the injection. Curshmann and Gaupp do not hesitate to attribute a leucolytic force to the leukaemic serum, due to a leucotoxin, the action of which is shown by a marked leucolysis four hours after the injection. This leucotoxic ferment only exists in the serum of irradiated leukaemics.'

An objection was raised by Capps and Smith (8) that it did not necessarily follow, because the irradiated leukaemic serum was leucotoxic to the white corpuscles of the rabbit, that it was therefore leucotoxic to the human white corpuscles, and especially to those of leukaemic patients.

In reply to this objection the following experiment by Curshmann and Gaupp may be quoted: The serum from a leukaemic patient, who had been treated by radiotherapy at regular intervals for two years, was injected on repeated

occasions, during a period of three months, under the skin of another patient who had previously received no treatment of any kind. Each injection was followed by a destruction of the leucocytes very similar to that following radiotherapy. It was found that the leucocytes returned to their normal number more rapidly after each injection. Thirteen days elapsed after the first injection before a return to normal occurred, nine days after the second, and six days after the third. This is important, as it is in accordance with the generally acknowledged fact that radiotherapy in cases of leukaemia becomes progressively less effective after repeated treatments.

Ambrozio injected the serum from an irradiated rabbit into a normal rabbit, and also into a rabbit with hyperleucocytosis—leucocytolytic action supervened in each case, affecting chiefly the mononuclear cells, and especially the lymphocytes—and he found that the exposure to X-rays of the non-irradiated animal did not confer on the serum any leucolytic action. Ambrozio further experimented as follows: A dose of 4 H, very hard X-rays, was daily administered for ten successive days to the spleen and bones of a healthy young man. At the end of ten days a preparation of his blood was made, and 10 cc. were injected daily into a patient with acute leukaemia. In 24 hours a leucolysis appeared, very definite and very rapid, if the injection was made intravenously; slower and more lasting if the injection was made subcutaneously. Accompanying the leucocytosis there was an improvement in the white count, also an increased excretion of uric acid; the spleen diminished in size.

David and Desplats, as the result of their very careful and extensive research, formed the opinion that the direct destruction of the haematopoietic tissue did not explain the action of radiotherapy in leukaemia: on the contrary, the changes in the haematopoietic organs were secondary to a destruction (direct or indirect) of the white corpuscles circulating in the blood. They give the following reasons:

(1) **The destruction of the haematopoietic tissue theory**

(the theory of Heinecke). The therapeutic doses employed are insufficient to provoke a degeneration of the myeloid or lymphoid tissues. Post-mortem examination of animals after irradiation with doses corresponding to those of therapy shows no marked degeneration changes in the haematopoietic organs.

'The experiments and arguments of Aubertin and Beaujard appear to us to give amply sufficient reason for the rejection of the primitive theory of Reinecke, and we content ourselves with remarking that clinical experience is, in this instance, in full accord with experiment; the leucopenia excited by a series of radiations does not actually start always immediately after a seance, as it would if the action corresponded to a rapid destruction of the constructing tissue; we have on the contrary several times seen it start 8 or 10 days after the X-ray seances, by which time the degenerative lesions have had ample time to repair themselves. On the other hand, this leucopenia is not produced with abrupt suddenness, but it increases progressively for a certain number of days, intersected, perhaps, it is true, by some bursts of leucocytosis.'

(2) **The theory of the destruction of the white corpuscles circulating in the blood.** If the deeply situated organs do not receive a destructive dose, neither can the white corpuscles during the short time of their circulation, although it may be recurrent, through the field of irradiation, receive a sufficient dose to destroy them.[1] 'Can we imagine that a direct destruction of white corpuscles could be retarded for a period of three weeks or a month before it should show itself? Is it possible on such a hypothesis as this to explain why some seances of X-rays are followed

[1] This would surely depend upon the radio-sensibility of the leucocytes or the radio-sensibility of their nuclei, and the length of time that some of them were in the radiation field: both of these are unknown factors, but the radio-sensibility of the leucocytes is clearly very high, as is shown by the readiness with which they are destroyed in comparison with the red corpuscles, and some of the white corpuscles must be in the radiation field for an appreciable time.

by a considerable leucopenia', whilst other seances do not influence the composition of the blood at all?

'Finally, can we comprehend why in certain patients, as we have seen to be the case, in spite of repeated radiotherapy, the number of the white corpuscles progressively increases?'

(3) **The theory of leucolysins.** David and Desplats think that it is impossible at the present time to deny the existence of leucotoxins, or to deny the influence of X-rays on their appearance, or to invalidate their manifest action in diminishing the number of the white corpuscles. They raise, however, one objection to their being regarded as the curative agent in the radiotherapy of leukaemia, and this they regard as a very serious one to the acceptance of such a theory, namely, that the white corpuscles of certain patients are not reduced in number, and in some cases may even increase in number after the application of X-rays. Such cases appear to be very exceptional; David and Desplats have recorded one or two cases, and others have been recorded by Œttinger, Fiessinger, and Sauphar (9), and also by Provinciali.

David and Desplats sum up their very valuable treatise by the following conclusions:

1. The stimulating action of X-rays in small doses should be considered apart from their destructive action in large doses.

2. The destructive action of X-rays does not seem to have any relationship with a large number of the haematological and anatomical-pathological phenomena observed in the evolution of leukaemia treated by X-rays.

3. These phenomena are much more rationally explained by the stimulating action of X-rays.

4. The spleen and other haematopoietic organs are simultaneously stimulated in all their deficient functions, particularly in their leuco-destructive function, and in their haematopoietic functions, proportionately, on the one hand, to the dose of X-rays, and on the other hand, to the functional quality of the tissues excited.

5. This conception is not opposed to the existence of leucolysins circulating in the blood, but one may consider the leucolysins as the products of the secretion of the different macrophages in the blood, which vary with the dose and are proportional to the richness of the haematopoietic organs in macrophages.

They consider that it is 'definitely a vital reaction, by means of which the haematopoietic organ, affected by the leukaemic process, responds to the therapeutic stimulus; and this reaction leads by different mechanisms to a return towards the normal haemoleucocytolytic formula, which has been so profoundly disturbed'.

David and Desplats' arguments in favour of a double mechanism, the one constructive, the other destructive, simultaneously functioning, do not appear to offer either a probable or a satisfactory explanation of the therapeutic action of radiotherapy in leukaemia. A far more probable explanation appears to be that some leucocytes are destroyed: namely, those which happen to be exposed in the field of radiation whilst their nuclei are in a sufficiently radio-sensitive stage, and that as the result of the destruction of these leucocytes or their nuclei a leuco-toxin or ferment is produced, which exercises a destructive action on the white corpuscles in the blood, and possibly may induce changes in the spleen and other glands. The two objections which David and Desplats raise to such a hypothesis are far from insuperable. First, as regards the very rare cases in which no leucocytolysis or even a leucocytosis follows the radiation: it is surely by no means unusual to find exceptional cases which fail to react to treatment whatever the nature of the treatment may be, or are even made worse by a treatment which benefits the majority of patients: such idiosyncrasies are explicable on a variety of grounds.

The other objection, that leucocytolysis does not occur for 8 or 10 days after the treatment, is more in favour of than opposed to the theory of the formation of a toxin resulting from the destruction of a certain number of leucocytes.

Such a delayed occurrence is analogous to the skin reaction following a full pastille dose of X-rays, and the liberation of a toxin resulting from the destruction of the nuclei may explain the delayed occurrence in each case.

The strong point in favour of such a theory is the very definite and distinct evidence that such a toxin is formed as the result of exposure to X-rays. It is far easier to conceive such toxins as resulting from the destruction of the leucocytes or their nuclei by X-rays than to regard them as produced by the secretion of macrophages circulating in the blood in variable quantities.

It is interesting to find in the progressive rapidity with which the leucocytes return to their normal numbers after successive injections of serum from irradiated patients, a condition analogous to and to some extent explanatory of the progressively decreasing efficiency of therapeutic radiation when applied to a patient in successive courses. It appears to suggest the formation of an antitoxin.

It is very important from the point of view of therapeutical technique to arrive at a definite conclusion, as to whether the X-rays act on the spleen or on the circulating white corpuscles: it is, perhaps, best in the present state of our knowledge to continue the custom of irradiating the spleen, for, in any case, a large quantity of blood circulates through the field of radiation in that area, and it is not impossible that the white corpuscles may undergo some change in that organ which may render them specially radio-sensitive. On the other hand, the unfortunate occurrence of leucopenia in X-ray and radium workers strongly suggests a form of radiation, prolonged, of low intensity, and administered to the body as a whole.

**Hodgkin's Disease.** The enlarged glands of this complaint yield readily to radiotherapy of moderate intensity. The permanency of the results is very uncertain, and patients so treated appear to be especially vulnerable to septic infection.

**Exophthalmic goitre.** If, as appears to be incontestable, the radiation of hard X-rays, or the gamma rays of radium,

has a restraining influence on glandular secretion, and if 'the arguments in favour of the hyper-secretion theory of this disease appear to almost all observers to be of overwhelming strength' (Rendle Short), then both radio- and radium-therapy may be described as exercising a specific action in this disease.

So far as my personal experience and observation extend, it appears that the success of this treatment depends, as is so commonly the case in other diseases, upon its early adoption.

If drug therapy and other forms of treatment are persisted in, in spite of their inefficiency, until the disease has reached an advanced stage, then radiotherapy will frequently fail. But if radiotherapy is adopted in the early stages of the complaint, both the symptoms and the physical signs will quickly disappear. As regards the permanency of the results obtained in such conditions as this, the exciting cause of which is not fully understood, it is very difficult to speak with both correctness and dogmatism.

The technique of the radiotherapy of Graves's disease differs in no essential respect from that already described in the treatment of the ovaries in cases of uterine fibroids.

Since the thyroid gland in this disease reaches its state of maximum enlargement about the time of the menstruation, this would appear to be its period of greatest radio-sensibility, and consequently indicates the special need for treatment during such activity

**Tuberculous and other glands.** Enlarged and diseased glands react to radiation from X-rays or the gamma rays of radium in proportion to their metabolic activity, in accordance with the theory of Regaud.

The most quickly and readily affected glands are those which are enlarged as the result of simple inflammatory changes. Lympho-adenomatous glands are the next in order of radio-sensibility: and then in sequence follow the sarcomatous, tuberculous, and carcinomatous glands.

Tuberculous glands, though coming third on this list,

are often capable of being very successfully treated by X-rays. A most exhaustive paper on this subject, 'Le Traitement radiothérapique des Adénites chroniques bacillaires', was communicated by Dr. Max Roques (10) to the Congrès de l'Association Française pour l'Avancement des Sciences, held at Nîmes, August 1912.

The following are some of the conclusions at which Dr. Max Roques arrived: That the X-rays have no direct action on the bacilli. That they exercise an indisputable action on the diseased tissue cells. That they exert a destructive action on the leucocytes, on the lymphoid cells, and on the diseased elements generally. That they appear to excite proliferation of the connective tissue cells. That radiotherapy clearly exercises a favourable influence on those forms of chronic adenitis which are regarded as due to tubercle bacilli, and that this favourable action is shown by the marked diminution of the swelling which almost invariably occurs, and frequently even by its complete disappearance; by the drying up of the suppuration; by the rapid cicatrization of the ulcers and fistulae; by the removal of the keloids; and by an aesthetic result better than can be obtained by free incision and drainage. He considers that the treatment is contra-indicated when there is a condition of hypo-thermia, when the disease is too advanced, and where the infection is generalized. He advocates the employment of radiotherapy for intra-thoracic glandular involvement which is occasioning pressure symptoms, and in abdominal involvement where operative treatment is contra-indicated, and in which the general condition of the patient is not too seriously affected. He regards the treatment as exercising a very favourable influence on the general health of the patient.

In the treatment of tubercular glands ultra-violet radiation has largely superseded the application of X-rays. For cervical adenitis the tungsten arc should be applied locally to the neck so as to produce a second degree erythema, and the tungsten or carbon arc should be applied to the back to a degree sufficient to yield a first

degree erythema. Tubercular peritonitis is also usually much benefited by U.V.R.

**Cancerous glands.** The efficiency of the present methods of radiotherapy is insufficient to justify its adoption in the case of glands which can be removed by operation: but it is, nevertheless, of considerable value in the treatment of inoperable cases. The most marked effect of radiotherapy in these cases is the relief of pain. This result, which is alone sufficient to justify the adoption of the treatment, is probably due to the action of the radiation on the inflamed connective tissue cells rather than to a direct action on the cancer cells.


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# CHAPTER VII

## DISEASES OF THE SKIN

DISEASES of the skin are in many instances quickly and readily cured by electrical methods, even after the customary remedies have been applied for long periods without success.

It is the chronic and atrophic forms of skin diseases rather than the acute and inflammatory that yield most readily to electrotherapy. The chronic conditions, such as alopecia areata, psoriasis, chronic eczema, in which the blood supply and nutrition of the skin are at fault, are specially amenable to the stimulating influence of powerful ultra-violet radiation or small doses of X-rays. Electrotherapy, in such cases, strikes directly at the cause of the trouble by causing a superficial hyperaemia which speedily restores the efficient nutrition of the skin.

In alopecia areata, for instance, the smooth, shiny, anaemic, atrophic appearance of the skin is in a short time after the application of powerful ultra-violet radiation replaced by skin of normal appearance; and if the hair follicles have not completely atrophied, a new growth of hair quickly appears. It is difficult to make too high claims for ultra-violet radiation in the treatment of this condition, and it may with accuracy be stated that if a regrowth of hair is possible, it can be obtained more quickly, with greater certainty, and with less inconvenience to the patient, by means of ultra-violet radiation than by any other means (Figs. 29, 30). There is one essential to this treatment, that is, that the radiation employed must have the necessary energy; some of the instruments sold for this treatment are of such diminutive power that they cannot provide the necessary output. In order to obtain the best results, the energy should not be less than that yielded by a current of 15 amperes across the arc. The application should be made at a distance not greater than 12 inches from the arc for at least five minutes, and

FIG. 29. Case of alopecia areata before treatment.

FIG. 30. The same patient after three months' treatment by ultra-violet radiation from the tungsten arc.

must result in a marked hyperaemic reaction. Chronic eczema often yields readily to ultra-violet radiation; if this treatment fails, as it will sometimes do in old-standing cases, weak doses of X-rays, about one-third of a pastille, should be employed. The previous application of ultra-violet radiation materially assists the action of the X-rays, enabling a similar effect to be produced with a smaller radiation. The action of the X-rays in the small doses employed in the treatment of eczema is a stimulating one. The X-rays may, if it is preferred, be administered through a thin aluminium filter; but in that case their action is still due partly to the soft rays, namely, the residual soft rays that pass through the filter. That a minimum of soft X-rays actually passes through the thickest filtration is shown by the skin reaction that occurs after radiation by the Wintz method, in which a filtration of 12 mm. of aluminium is employed with an exposure for thirty-five minutes.

Pustular eczema, or impetigo in the milder and more recent forms, speedily yields to ultra-violet radiation; for the success of the treatment, however, it is absolutely essential that all crusts should be removed. In cases of long duration, or where there exists difficulty in the complete removal of the crusts, a preliminary course of treatment with zinc electrolysis should be given, using a weak galvanic current, and an active positive electrode of zinc applied over the ulceration through a pad soaked in a 2 per cent. solution of sulphate or chloride of zinc. When the affected parts have been thoroughly cleaned in this manner, ultra-violet radiation is the most speedy method of completing the cure. The static breeze should never be applied to the skin when it is in a pustular state; for this powerful current has the effect of scattering the germs and infecting the neighbouring areas of the skin.

**Tinea cruris.** The fungus of this condition appears to be on or sufficiently near the surface of the skin to be reached by the ultra-violet radiation, and, if proper precautions are taken to prevent reinfection from the

clothing, a cure may often be brought about by a single treatment from the tungsten arc. Usually, however, difficulty will be experienced in accomplishing the necessary disinfection of the clothes, and in such cases white precipitate ointment should be rubbed on the treated parts to prevent their reinfection between the radiations.

Ringworm of the face can often be cured by ultra-violet radiation; but the more deeply seated ringworm of the scalp will need the more penetrating X-rays for its destruction. The treatment of ringworm of the scalp has almost developed into a speciality of its own, and it appears to be passing from the control of the medical profession into the hands of lay operators. The general adoption of X-rays for the treatment of ringworm appears to be due more to the definite period which can be fixed by its employment for a cure, and hence for the return of the patient to school, than to any real therapeutic necessity. In a fairly extensive experience of this trouble among school children of the dispensary class, I cannot recollect having had any special difficulty in curing ringworm by the simple method of applying Ung. Hydrarg. Ammon., making sure that the ointment was rubbed in night and morning, the old ointment being thoroughly removed before the fresh was applied. The routine application of X-rays in these cases is taking a very large hammer to crush a very small nut, and it is certainly a procedure that is attended with appreciable risk of permanent baldness.

Acne yields very readily to ultra-violet radiation; the reaction aimed at should be regulated according to the duration of the eruption and character of the comedones. If the spots are of recent occurrence and are small in size, an erythema of the first or second degree will be sufficient: but, if they are pustular, indurated or of long standing, an erythema of the second or third degree will be required to effect their removal. In very old-standing cases, a mild dose of X-rays, one-sixth to one-third of a pastille may hasten the disappearance of the spots, but provided that

strong doses of U.V.R. are employed, the application of X-rays is very rarely called for.

X-rays have been used in the treatment of acne in two degrees; in a mild form to exert a stimulating action on the skin, and in a more intensive form to destroy the skin glands. Great care should be exercised not to carry the latter form of treatment too far, otherwise a dried-up parchment-looking skin will result, which is almost more unattractive than the acne pustules themselves.

I have seen one case of this parchment skin in a young woman, occasioned by excessive X-ray dosage, much improved by the application of ultra-violet radiation.

**Prurigo.** The milder forms of this troublesome affection may often be relieved by the application of ultra-violet radiation; the more severe forms will require X-rays, and will not always be relieved by their use.

**Chilblains, Angeio-neurotic Oedema, and Raynaud's Disease**. Chilblains are best treated by the sinusoidal or galvanic currents. When the hands are affected, a pair of loosely fitting gloves should be made of Turkish towelling, and attached to the end of the finger and thumb partitions there should be a small pouch or bag into which the electrode is inserted. In this manner the lines of force of the current are correctly distributed over the affected area. If the galvanic current is employed, 10 to 15 ma. should be administered for forty minutes. When the sinusoidal current is administered its strength should be within the easy toleration of the patient, it should be administered for about thirty minutes, and it should not be of sufficient strength to excite contractions. Ultra-violet radiation, administered in combination with either of these currents, materially assists in producing an early cure. The static breeze is indicated where there is much swelling or stiffness of the fingers. Chilblains of the feet may be treated by a modified form of glove, or by foot baths.

One of the most effective methods of dealing with chilblains is by means of contrast baths, and their use

should be associated with any form of electrical treatment that may be adopted for this condition. The routine employment of contrast baths during the autumn, before the chilblains begin to appear, will usually prevent any trouble of this nature occurring: in cases with a history of chilblains recurring each winter this prophylactic measure is of great value.

The technique for the utilization of contrast baths is extremely simple. Suitable vessels for the hands or feet, as may be required, are procured. Two vessels are required for each hand or foot; one of these is filled with water as hot as can be tolerated, the other with water as cold as can be obtained. The foot or hand is plunged into the hot water and kept there until it has become accustomed to the heat, about one minute, and is then suddenly withdrawn and plunged into the cold water. This procedure is repeated for about ten or fifteen minutes, the treatments being administered night and morning.

By employing four baths both hands or both feet may be treated simultaneously.

Angeio-neurotic oedema is usually appreciably benefited by the sinusoidal current; the oedema and stiffness can usually be to some extent reduced by the static breeze.

Raynaud's disease is generally much benefited by the stimulating action of the sinusoidal current combined with ultra-violet radiation and the static breeze.

**Lupus** may often be apparently cured by powerful and prolonged ultra-violet radiation. The tungsten arc should be employed with at least 15 amperes across the arc, and the radiation should be sufficient to produce an intense reaction, and preferably a blistering of the area treated. The treatment should be applied twice a week at first, afterwards once a week, and from time to time periods of rest should be given to prevent over-treatment, and in order to see the effect of the treatment after the erythema that it excites has subsided.

It has been urged that the Finsen lamp is superior to the mercury vapour lamp in the treatment of this con-

dition, because the most effective part of the radiation is assumed to be in the more penetrating rays situated towards the violet end of the ultra-violet spectrum, a portion of the spectrum in which the mercury vapour lamp is comparatively deficient. This argument does not, however, apply to the tungsten arc lamp, for its radiation is very powerful in the region of the spectrum referred to; and there is no physical, clinical, or other reason why the tungsten arc lamp should not be equally effective as the Finsen lamp, provided that it is applied for a sufficient length of time and with sufficient intensity.

The radiation from the tungsten arc should be applied by means of a quartz condensing lens to small areas and to lupus nodules; for the treatment of large areas the reflector should be employed.

A preliminary destruction of the larger lupus nodules by indirect diathermy, before the application of the radiation, materially aids the treatment.

Radiotherapy has in the past been employed extensively in the treatment of lupus, but its employment is not free from danger. It has been asserted on high dermatological authority that, since the introduction of the treatment of lupus by X-rays, the percentage of cases that develop malignancy has much increased. If this is the case, the reason is obvious. Many cases of lupus recur again and again, and are more or less continuously treated over a period of twenty or thirty years. The treatment is of an irritating character. Can we be surprised, if irritation, as is generally admitted to be the case, stands in a most intimate causal relationship to cancer, that, when to the irritation of years of curetting and ointments the far more powerful irritation of repeated doses of soft X-rays is added, the growth suddenly flares up into a rapidly extending cancer?

Lupus is so prone to relapse, or to recur in other areas, that only an inexperienced or unduly optimistic operator will speak of permanent cures.

Warts, moles, epulides, capillary naevi, urethral car-

uncles, and similar growths are best treated by the indirect method of surgical diathermy.

In this treatment the patient lies on a condenser couch, consisting of one or more sheets of zinc or other metal covered and overlapped at each edge to the extent of an inch by a vulcanite sheet of about $\frac{1}{16}$ of an inch in thickness. He holds an electrode in each hand, the metal plate of the condenser couch being connected with one terminal of the diathermy apparatus, and the hand electrodes with the other terminal; a current strength, measured by a hot wire amperemeter of about 300 ma., is passed, and oscillates through the patient's body with very high frequency. The operator holds in his hand a suitable instrument, such as an aneurysm needle, or a primus pricker, with no wires of any kind attached to it, and applies its point to the part to be destroyed. The current with which the patient is charged inductively attracts a current of similar frequency from the capacity of the operator, and this oscillating current is concentrated on the part to be coagulated with such intensity that it is rapidly and almost painlessly destroyed. If the growth to be removed has a narrow pedicle, the heat is concentrated in its narrow stem, so that the portion to be removed drops away from its base. In dealing with such pedunculated growths it is best to hold them with a pair of artery or sinus forceps in place of applying the pricker.

The method is so free from pain, leaves no scarring, can be so accurately and delicately regulated, and its action can be so clearly watched throughout the application, that it forms an ideal method of removing these small growths.

Indirect diathermy is also the best method of dealing with corns.

In the case of corns on the feet, the patient does not hold the electrodes, as by such a method insufficient current would pass to the soles of the feet. In this case an electrode with moist pad is attached to the dorsum of

the foot, and a current of about 500 ma. is passed. A pointed metal electrode is held by the operator to the surface of the corn, until by a leaky condenser effect, it is seen to light up on its under surface. The corn will not be removed at once, but will drop off, leaving a healed surface, in about three weeks. Meanwhile the destroyed corn acts as a protective covering to the underlying tissues whilst they are healing. If the corn is a large one, it may be necessary to treat it at two or three points of contact.

This procedure is very effective and usually causes very little pain either at the time of its application or subsequently.

**Hypertrichosis.** The removal of superfluous hairs is usually practised by destroying the hair follicle by electrolysis. The other methods are by X-rays and by diathermy.

Electrolysis is a troublesome, painful, and on the whole an unsatisfactory procedure, and more than 10 per cent. of the hairs so removed return. This is probably a form of treatment that is better performed by a 'beauty specialist' than by the ordinary electrotherapist.

X-rays are useful in some cases; the efficacy of this method is clearly seen in those cases of ringworm in which an overdose of the radiation has been followed by permanent baldness. Thick and really unsightly hairs often require a very large and dangerous dose of X-rays to secure their permanent removal. The downy and 'beautifying' hairs are the most readily removed by X-rays, and are consequently always absent after an efficient treatment; the skin therefore never recovers its former appearance, and many of the ladies who present themselves for this treatment should be advised to endure the presence of a slight moustache rather than incur the risk of worse troubles.

In the depilation of hairy moles, the hairs of which are very coarse and disfiguring, I have found diathermy the most efficient treatment.

Diathermy is a most powerful depilator; when treating port wine stains of the eyebrows I have been unpleasantly surprised at the ease with which the hairs of the eyebrow can be unintentionally removed.

For the depilation of coarse hideous hairs I employ indirect diathermy; a primus pricker is applied over the exit of the hair, a small diathermy current is turned on, and slight pressure is made on the pricker. In one or two seconds the pricker will be felt to slip through the skin, the depth of the hair follicle is then reached, and when a slight discoloration appears round the point of the pricker, the current is cut off and the instrument removed. This method will permanently epilate the thickest hair, it will be followed by little or no scarring, and is less painful than electrolysis.

Hyperidrosis is best treated by lightly filtered X-rays. The technique presents no special features.

**Boils, carbuncles, abscesses, and ulcers.** Ulcers and the other conditions named, when their cavities have been thoroughly exposed by incision, are best treated by ultra-violet radiation. Wounds and varicose ulcers of the legs, when their surfaces are clean and free from crusts, do remarkably well with this treatment. Often it is necessary to clean the ulcers by a preliminary zinc electrolysis.

The treatment of the cavities of boils and carbuncles by zinc electrolysis usually results in rapid improvement. Crops of boils may frequently be cut short by strong ultra-violet radiation.

The very acute pain that occasionally occurs in partially cicatrized varicose ulcers is best treated by the sinusoidal current. Ultra-violet radiation and X-rays are also useful in such a condition.

Scars and keloids are most effectually treated by radiotherapy. Occasionally considerable pain will be produced on movement as the result of dragging on muscular fibres which have become partially involved in scar tissue; the powerful contractions excited by the Morton wave current break down such adhesions and

remove the pain. Such a condition was frequently met with in wounds of the back during the war. I have seen a deep sulcus transversely placed across the anterior surface of the thigh, due to scar involvement of the muscular fibres, entirely removed by the Morton wave current.

## CHAPTER VIII

## THE DISEASES OF THE ORGANS OF SPECIAL SENSE

THE treatment of these organs, whether by electricity or other means, more properly belongs to the specialist within whose province they fall than to the general electrotherapist. It is far easier for the oculist, the laryngologist, and the aurist to learn the nature and application of the electrical remedies relating to their specialities than it is for the electrotherapist to acquire an accurate knowledge of the diseases of the eye, throat, and ear, and to become skilled in the use of the ophthalmoscope, the laryngoscope, and the ear speculum.

It would doubtless well repay such specialists, by visiting a well-equipped electrical department, to ascertain what electrical methods might be of service in their specialities.

Ultra-violet light and diathermy would probably be useful to the oculist. Surgical diathermy, both in the direct and in the indirect methods, has already proved of great service to the laryngologist. In diseases of the ear, the electrolytic action obtained from the application of galvanism with a solution of a zinc salt has already proved of the greatest value in the treatment of chronic otitis media, in the same way that a similar form of treatment has proved useful in the treatment of other suppurating cavities.

These remarks particularly apply to the application of electrical methods by means of, or in conjunction with, the use of special instruments, such as the application of surgical diathermy to intra-laryngeal growths, a form of treatment that necessitates the simultaneous use of the laryngoscope. The treatment of such conditions as suppurative otitis and ozaena by zinc electrolysis can be efficiently carried out in any well-organized electrical department.

**Hypertrophied Tonsils, Follicular Tonsillitis, Granular Pharyngitis, Pendulous Uvula.**

All these conditions can be greatly benefited by surgical diathermy. It is a most dangerous procedure to attempt the removal or the complete destruction of the tonsils by diathermy owing to the proximity of the carotid artery. In the treatment of septic or enlarged tonsils, however, it usually suffices merely to destroy the surface of the tonsil by the application of a diathermic current, of 300 to 500 ma., for 2 or 3 seconds, at four or five different points on the surface of the tonsil.

In this way the superficial septic lining is destroyed and a subsequent shrinking of the tonsil ensues.

The depth of destruction by this method does not exceed a few millimetres and the procedure is consequently free from danger.

The tonsil may be previously painted with a 10 per cent. solution of cocaine, but the operation is so painless that even this is usually unnecessary.

I have treated about twelve cases in this way and in each instance a lasting cure resulted. In only one of these cases was any subsequent pain experienced, and then it only amounted to a slight aching behind the ear of very brief duration.

Dr. Delinger[1] has recorded 150 cases treated by a very similar technique. He employed a needle electrode, inserted about $\frac{1}{8}$ inch, and switched on a current of 2,500 ma. for one or two seconds. Delinger covered the tonsil with punctures about $\frac{1}{4}$ inch apart, treating only one tonsil at a time, and making about 4 punctures at a sitting. He recommends the method as preferable to tonsillectomy.

Diathermy has been recommended in certain cases of chronic deafness. The best method of administering the current in these cases is for either the operator or the patient to hold an electrode in each hand and insert a forefinger into each meatus; in this way, by the heat felt in the

[1] Delinger, *Med. Journal and Record*, May 18, 1927.

finger, the current can be safely regulated. Pain in the ear can also be alleviated by a similar procedure.

Blepharitis, conjunctivitis, corneal ulcers and other diseases of the eyes can often be cured by the constitutional administration of U.V.R. to the backs and abdomens of the patients. In fact it was by the good results obtained from this treatment at the London Hospital that the action at a distance or the constitutional effects of U.V.R. were first clearly established.

# CHAPTER IX

## ELECTRICITY AS A SURGICAL AGENT

LARGE malignant growths have been destroyed, and satisfactory results have been recorded by the employment of the caustic action of the products resulting from electrolysis. In these cases, chiefly carcinoma of the breast, zinc needles, coated with an amalgam of mercury, are plunged into the tissues to be destroyed. A bipolar method, in which two sets of needles are connected to the respective poles of the current supply, may be utilized; or a monopolar method may be used with an active and a large indifferent electrode. Dr. Massey, of Philadelphia, to whom we owe this method, has worked out its details in the most careful and exhaustive manner; he gives the following table of the 'Maximum currents safely applied by the Monopolar Method.

| | |
|---|---|
| To the head, mouth, throat, and neck | 300 to 400 ma. |
| To the left breast | Minor monopolar applications only. |
| To the right breast and thorax generally | 400 to 800 ma. |
| Below the waist | 800 to 1,600 ma.' |

The tissues in the neighbourhood of the needles are destroyed by the caustic action of the nascent double salts of mercury and zinc formed as the result of electrolytic action.

Dr. Massey has published many records and photographs clearly illustrating the success that he has obtained by this treatment: but owing to the complicated technique and the danger associated with the employment of such high constant-current intensities, the method is not likely to come into general use.

### The Surgical Uses of Diathermy

It is in minor surgery that surgical diathermy finds its most common application. It is capable of such delicate regulation that even the most superficial and the smallest of naevi can be removed by this method with the minimum

of destruction and scarring. It is, on the other hand, so powerful that the most extensive surface growths can be removed by its use. Its direction is so certain and unvarying that the extent of the destruction can, by suitable technique, be confined to any required depth from the surface.

It should be distinctly understood that this method is one solely of tissue coagulation by heat: it is not a burning, a charring, or an incineration. The current should invariably pass in a conductive manner without the appearance of any sparks; whenever the current becomes disruptive and sparks begin to pass, burning of the tissues immediately commences, and then haemorrhage may occur.

Burning and incineration of the tissues by heated irons and Paquelin cauteries have been rightly relegated to the surgical barbarities of the past, largely as the result of the danger of primary or secondary haemorrhage that results from their employment. In the correct application of diathermy the tissues are 'properly cooked' or coagulated, and the vessels beneath the destroyed tissues are permanently sealed.

The treatment may be applied by either a monopolar or a bipolar method. In the monopolar method a large indifferent electrode is applied at some convenient spot and connected with one of the terminals of the apparatus: a more convenient method is to employ a condenser couch in place of the indifferent electrode; no harm can then result from imperfect apposition, and no disturbance of the patient's clothing is involved. To the other terminal of the apparatus, an electrode terminating in a small metal point is attached; this point is applied to the tissue to be destroyed, and a current of from 200 to 500 ma. is switched on by means of a foot switch. A foot switch is absolutely necessary for the proper performance of the operation. The diathermic current, distributed over the large surface of the indifferent electrode, causes at most a mild sensation of warmth; but, by means of the small

metal point of the active electrode, it is concentrated or focussed on the tissue with sufficient density rapidly to cause its coagulation.

The depth to which the coagulation takes place can be regulated by the intensity of the current and by the time during which it is applied.

A diathermy current of too high an intensity will rapidly char the superficial tissues, and will then lead to the passage of the disruptive sparks which it is so important to avoid. A current of weaker strength, applied for a longer time, will lead to a deeper coagulation with no burning or charring of the tissues. This is the result to be aimed at.

It has been alleged, and perhaps with reason, that diathermy applied in this manner is too blind a procedure to be applied to many regions and for the treatment of many superficial conditions: for there are no means of ascertaining either with certainty or exactitude the depth to which the coagulating process will extend; and consequently important structures, such as subjacent nerves and ducts, may be unintentionally destroyed, or large vessels may be imperfectly coagulated, their walls laid open, and dangerous haemorrhage set up.

These objections may be met by the employment of the bipolar method in cases where it is important definitely to limit the action of the current.

The bipolar method may be applied in two ways: either by the employment of two small button-like electrodes of equal size—in this case a superficial line of coagulation of a width equal to the diameter of the electrodes extends across the points of application. Or an active electrode, formed by eight to ten needles, secured to a small metal plate, may be inserted to the depth to which it is desired that the coagulation should extend.

I generally get such electrodes made by a tinsmith to suit the particular type of case which I am about to treat. In the treatment of the thickened and spreading circular edge of a large epithelioma of the skin, this type of active

electrode is specially useful. The needles of the electrodes are inserted to the depth to which the coagulation should extend in the thickened edge of the growth, about an inch apart. The current is turned on, and when the intervening tissue has been destroyed the current is switched off and one of the electrodes is removed and inserted on the other side of the remaining electrode, and the process repeated, each electrode in turn being moved round, until the whole of the thickened edge has been destroyed. In this manner complete destruction, extending only to the required depth, is secured. In the treatment of such a growth as the one referred to, a large indifferent electrode is then applied, and a small active one run over the centre of the growth.

For the removal of such a structure as the tongue, a small flat spatula with a rounded blunt edge is lightly applied at the point at which it is desired to remove the tongue, and a current is applied of such a strength as slowly to coagulate the tissues. In this treatment the points to be avoided are undue pressure on the spatula and the occurrence of any charring.

The more severe operations of surgical diathermy are followed by considerable reaction in the surrounding tissues, the most marked feature of which is the oedema which is occasioned. This subsides in a few days, but may occasion serious inconvenience or even danger in such regions as the throat, and may call for a preliminary or subsequent tracheotomy.

Diathermy is an ideal method for dealing with certain intravesical growths. More skill, however, is required in the manipulation of the urethroscope than of the diathermy apparatus: its application therefore in such regions more properly belongs to the province of the urologist than to that of the electrotherapist.

The direction of the coagulating current in the application of surgical diathermy can be best ascertained by experimenting on a piece of raw liver, and Nagelschmidt rightly insists that such experiments should invariably

be performed by an operator before he attempts to treat a patient by this method.

A very instructive experiment is to take a chunk of liver about 2 inches thick, and to apply to two opposite sides of it a circular electrode of about one inch in diameter; after passing a current of 1 or 2 amperes through such a piece of dead tissue for a few minutes, the circular mass of liver, intervening between the two electrodes, will be found to be uniformly cooked or coagulated. The diameter of the coagulated tissue will be found to be very slightly greater than the diameter of the electrodes, this slight difference being due to the conduction of heat from the heated tissues and not to any diffusion of the current.

Another instructive experiment is to place a little raw egg albumen in a saucer, and to insert into it two needles, separated from one another by about 2 inches, respectively attached to the two terminals of the apparatus; a very weak current is gradually passed. The albumen will first commence to coagulate at a point in the centre, equally removed from the two needles, and will then gradually extend to the needles. This experiment shows that so far from the needles themselves becoming hot, and so heating the albumen by conduction, they, on the contrary, serve to dissipate some of the heat generated, so that the albumen in contact with them is the last to coagulate.

Provided that the operator retains the most elementary knowledge of anatomy from his student days, and refrains from applying the destructive diathermic current immediately over or in close proximity to important nerves and blood vessels, surgical diathermy is as safe and harmless as any operative procedure can be. In the after-treatment, the superficial wounds, resulting from the destruction of small lesions, are best treated by allowing the wound to heal under the aseptic crust resulting from the destroyed tissue. If this is impossible, as it generally is where there has been extensive destruction of tissue, the more simple the dressing the better is usually the result. Such wounds as a rule heal with very little pain, but there is often con-

siderable swelling accompanied by profuse oozing of serum. Following the application of surgical diathermy to the larynx or oesophagus the resulting oedema may be so severe as to necessitate tracheotomy, and, in some cases, it may be necessary to do a preliminary tracheotomy; such cases, however, belong to the surgeon rather than the electrotherapist.

The scars resulting from surgical diathermy are usually soft and flexible.

# CHAPTER X

## PRACTICAL HINTS AND METHODS

THE following instructions and hints are intentionally of a dogmatic character, and it must not be assumed that they are either the only methods to adopt or even the best methods: they are merely those methods that experience has led me to adopt in my own practice.

Though it is not essential to the administration of electrical treatment that the electrotherapist should have any mechanical skill, yet an elementary and practical knowledge of soldering, the possession of and the ability to use a small lathe, and some manipulative skill in the use of the ordinary metal-working tools will often save considerable expense, and, what is far more important, will prove the means of avoiding much loss of time in the repair of an apparatus that has suddenly broken down. Moreover, such knowledge and manipulative skill will add considerably to the electrotherapist's interest in his work, will enable him to understand the practical details in the construction of the instruments he employs, and will assist him in designing small but useful additions to his equipment. Perhaps the most useful of all these accomplishments is the art of using the soldering iron effectively, and this, by the aid of an electrically heated iron, is by no means difficult.

In the construction of electro-medical instruments, as in the case of all other mechanical appliances, simplicity of design and accessibility to the component parts are of the greatest importance. Many electrical instruments are designed too much for the sake of appearance, and the wiring and working parts are hidden away in a manner that renders the tracing and repair of any defect a matter of considerable difficulty and also leads to much waste of time.

**The Practical Administration of the Constant Current**

The instruments and appliances for the administration of the constant current need only be of the simplest and most inexpensive character.

The constant current may be derived for medical purposes from the D.C. mains, from accumulators, from dry or wet cells, or from the A.C. mains by means of a transformer which transforms the A.C. into the D.C.

Regulating instruments or resistances are needed to reduce the current from the source of supply to safe and therapeutic strengths.

By far the best instrument for regulating the current from the D.C. main is the Leduc shunt water resistance. This instrument was first described in this country in a paper, 'The Organization of Electrotherapy in Military Hospitals' (*Proc. Roy. Soc. Med.*, December 1915), by the late Dr. Ettie Sayer. Describing a visit that she had recently paid to the French war clinics, Dr. Sayer remarked, 'With regard to ionic medication, I would like to mention that Professor Leduc is now employing water instead of wire resistances throughout his district. This has the advantage of making the continuous current from the main perfectly safe, and so obviates the necessity for the installation of cell batteries.' Dr. Ettie Sayer also gave so clear a description of the Leduc instrument that, much impressed by the utility of such an appliance, I had no difficulty in getting a local mechanic to make me a similar instrument. Since that time I have used no other means of regulating the current from the D.C. mains. I have made certain modifications in the construction of the apparatus and the following is a description of the type of instrument that I now construct for myself and employ in my practice. The description is given in detail and there should be no difficulty in its home manufacture or in getting one constructed by a local mechanic.

Structural details of the Leduc Shunt Water Resistance (Fig. 32).

Materials required:

A circular earthenware pneumatic trough, obtainable from Messrs. Baird & Tatlock, Hatton Garden, London.

Measurements:

Inside diameter 10½ inches.
Inside depth 5½ inches.
Outside height 6 inches.

4 feet of one-inch square oak picture-framing with the rebate planed off. 2 feet of circular brass rod ⅜ inch in diameter. Four ¼ inch brass washers. Four ¼ inch brass nuts. One gas union with two locking nuts. One 3½ inch long ¼ inch Whitworth pitch brass screw with two locking nuts. A short length of ordinary double 5 ampere lighting flex.

A fixed outside cross-piece, AA, 13½ inches long, is firmly fixed across the trough by means of two small one-inch wooden blocks BB, grooved to fit the outside rim of the trough, and attached to the extremities of the outside cross-piece by two 1¾ inch screws, CC. The pneumatic troughs are not perfectly circular, and, if the fixed cross-piece is loosely adjusted to the point of narrowest cross-section of the trough, by a slight lateral twist it can be firmly attached to the trough, or by a reversed twist it can be released and readily removed from the trough.

Two lengths, 6 inches long, of brass rod, ⅜ inch in diameter, DD, threaded with ¼ inch Whitworth thread for 1½ inches of their upper extremities, are screwed into the fixed wooden cross-piece and are fitted with nuts and washers, EE. Two 5 inch lengths of the brass rod FF are tapped with ¼ inch Whitworth thread for the length of 1½ inches and are screwed into the extremities of the revolving cross-piece G and are fitted with nuts and washers.

A brass gas union K is screwed into the centre of the fixed cross-piece and is secured firmly in position by two locking nuts. Through the centre of this gas union a brass screw 3½ inches long, ¼ inch pitch, passes and is bolted by locking nuts above and below to the revolving cross-piece. This gas union joint is selected because it is a fitting readily obtained at any ironmonger and because

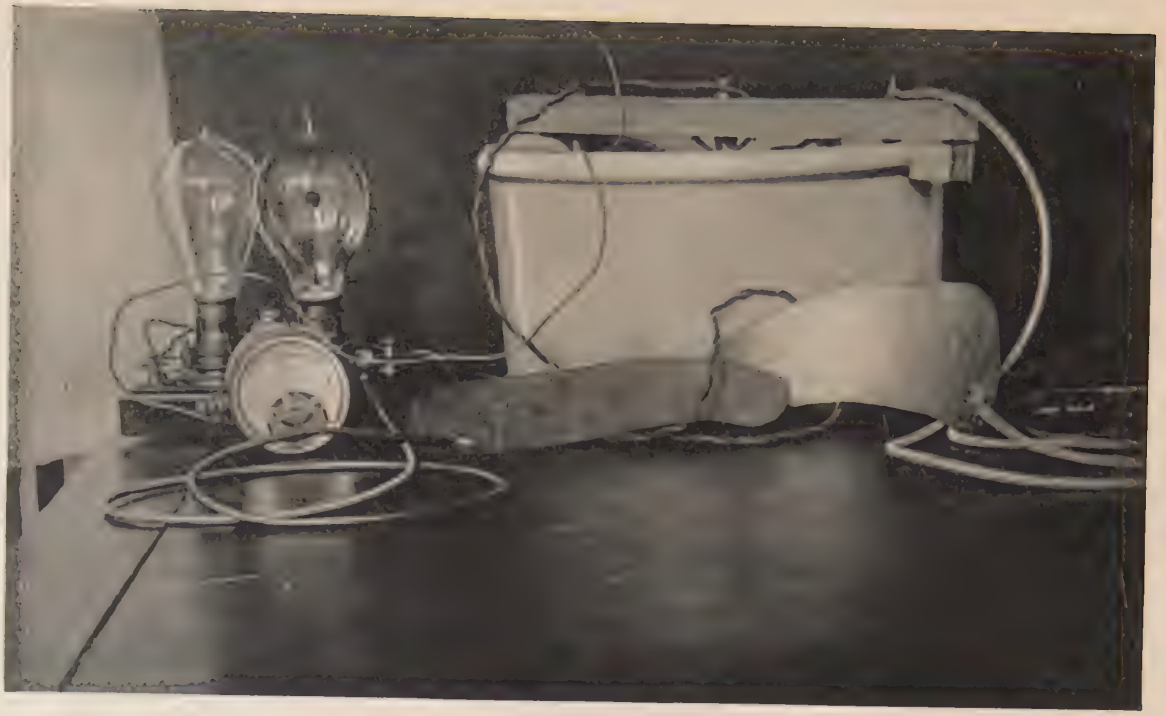

FIG. 31.—Photograph of shunt water resistance complete with galvanometer resistance lamps and knee electrodes

it affords a long bearing to the central screw, so preventing any lateral wobble in the revolving cross-piece. This is an important point in the efficient working of the apparatus. The wires from the main are led through the two holes NN in the fixed cross-piece and are attached to the rods FF in the revolving cross-piece by the nuts HH.

As an extra precaution the current from the main may

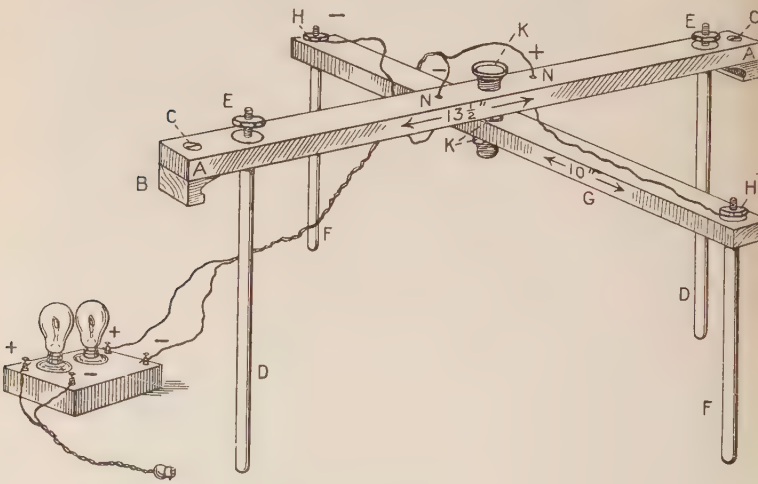


FIG. 32. Structural details of Leduc Shunt Water Resistance.

be led through two 32 C.P. carbon lamps, placed in series, to reduce the main voltage.

The patient's rheophores are attached to the nuts EE on the fixed cross-piece; in this way no movement on his part can affect the current strength, as might be the case if he were attached to the revolving cross-piece.

Sufficient water is placed in the troughs to cover the lower extremities of the rods to the depth of about one inch, and to this water a few crystals of potassium bichromate and a few drops of sulphuric acid are added to aid depolarization.

The polarity of the brass rods in connexion with the main can be readily detected by the hydrogen gas bubbles

which can be seen escaping from the negative pole, and by moving the revolving cross-piece accordingly the polarity of either electrode may be determined. A galvanometer may be inserted in series with the patient's rheophores.

With the revolving cross-piece of the apparatus at right angles to the fixed cross-piece the potential is at zero and no current flows. By moving the revolving cross-piece in either direction the current is gradually increased, and by revolving the cross-piece in the opposite direction the polarity of the current at the electrodes is reversed.

The safety of the apparatus is secured by the shunt path between the rods FF. The adjustment is very gradual, delicate and smooth.

The resistance of the water serves to damp out, rather than to increase by induction, as do the wire-wound resistances, the inequalities of current that always accompany the supply from the main generating dynamos: the effect of this is that the patient can tolerate with comfort a stronger current administered through the water resistance than when it is regulated through a wire-wound resistance. If the terminals of a telephone receiver are attached to the output terminals of a water resistance the ticking that is heard, due to the inequalities of the current, is very appreciably less than when the telephone receiver is attached to the terminals of a wire-wound resistance.

These shunt water resistances only cost about seven shillings to construct, and they are far more efficient than the elaborate wire-wound resistances costing several pounds.

**Accumulators.** The current derived from accumulators is a true constant current, and apart from the trouble of charging and attending to these rather perishable instruments, they are certainly the ideal source from which to administer the constant current in electrotherapy. Future improvements in their construction will probably lead to their increased use in medical electricity.

**Dry cells.** A portable battery for the administration of the constant current usually consists of an arrange-

ment of dry cells. The batteries sold for this purpose are usually very bulky, heavy and expensive.

A cheap, very portable and effective apparatus for administering the constant current may be easily constructed from the batteries now sold to provide the H.T. for radio sets. Formerly these batteries were all made in 3 volt steps from zero, but now most of them commence the first step at 20 or 30 volts or more. Such an initial step renders them useless for medical purposes: the old type can, however, still be obtained, and can be converted into portable galvanic batteries in the following simple manner.

Apparatus required: one 60 volt H.T. radio battery in 3 volt steps from zero, three 'wander plugs', and the usual electrodes and rheophores.

A radio wander plug is inserted at the zero negative plug hole, is connected with the patient's negative rheophore and remains unmoved during the treatment. Two positive wander plugs, A & B, are attached in series about an inch apart to the battery end of the patient's positive rheophore. At the commencement of the treatment wander plug A is inserted into the 3 volt hole of the H.T. wireless battery, and the patient receives a current at 3 volts potential. Plug B is then inserted into the 6 volt hole, the patient still receives 3 volts. Wander plug A is then withdrawn, and the patient receives 6 volts. Step by step this process is repeated until the desired voltage is reached. It should be remembered that, whilst plugs A and B are both inserted, the cell between them is being short-circuited and its charge is being quickly exhausted: therefore, after the insertion of one of these plugs the other should be withdrawn as soon as possible. The current is reduced or cut off by a step-by-step reversal of the above process.

On testing in the hospital electrical department a 60 volt H.T. battery, I found that 40 hours' intermittent treatment of a rheumatic knee joint with a current of 50 to 60 ma. was obtained before the battery showed any signs of exhaustion. The cost of such a H.T. battery with wander plugs complete is under ten shillings.

**Rheophores, Clips, and Electrodes.** These are most conveniently discussed together, for in their most perfect form they consist of but one unit.

I have found the rubber-covered low tension wire, 5 mm. in diameter, employed for the low tension wiring of motor bicycles, makes the best rheophores for the administration of the constant current, diathermy, faradism &c. It is clean, uncoloured, well insulated, flexible, durable and reliable, and so well fulfils the requirements of the electrotherapist.

After trying a variety of clips and terminals and finding them bulky and unreliable, I have entirely abandoned their use, and for the past few years have invariably employed electrodes directly soldered to the rheophores. I have found this a great improvement, as a soldered connexion of this kind is far less likely to become detached in use than any form of detachable clip, and the electrode can be more evenly and comfortably applied than when a clip is used. In order to use these soldered attachments, a different material had to be found from the usual tin or lead electrode which does not admit of hard soldering.

After experimenting with various materials, I ultimately hit upon a form of thin sheet brass which is readily obtainable at any ironmonger, where it is sold under the name of 'latten' for packing motor and other engine bearings. It is only 0·005 inch in thickness and is therefore very flexible. I find it very durable. Its present retail price is $4\frac{1}{2}d.$ a foot.

The method of soldering the electrode to the rheophore is of considerable importance. The wire of the rheophore should be bared of its rubber covering for about an inch, thoroughly cleaned and splayed or flattened out. It should then be soldered to the electrode, about half an inch from one of its corners, if of rectangular shape, or half an inch from the edge if the electrode is circular. Two small holes should next be pierced one on either side of the rubber-covered rheophore, and through these holes the rheophore, over its rubber covering, should be firmly bound to the electrode by very fine copper wire. If the rheophore is not

bound down in this manner, its twists and turns will soon break the soldered wires from their attachments.

A large selection of electrodes with the rheophores attached in this manner should be kept at hand ready for use. It is surprising what a saving of time and annoyance from fiddling with unsatisfactory clips is effected by the adoption of this method.

**The pads.** The pads should consist of Turkish towelling, of 4 to 8 thicknesses. This material is far superior to lint, being more elastic and not likely to 'ball' and harden, as are pads composed of lint. The Turkish towelling pads are very durable and can be washed; in the long run they are far cheaper than lint pads.

**Bandages.** Rubber bandages being elastic and insulating are much preferable to cotton bandages for securing the electrodes and pads in position.

### The Practical Administration of the Constant Current.[1]

Before turning on the current, make sure that all contacts and wires are firmly attached. Loose connexions may cause irregularity of the current and shocks and discomfort to the patient. Ascertain the polarity of the current. Make certain that the resistance is at zero. The condition of the skin area over which the pads are applied should have been examined before their application, and any small abrasions should have been covered with a film of collodion.

The pads should be well soaked in saline solution, the the exact strength of which is immaterial, and should be smoothly and evenly applied without any creases. The uneven application of the pads may lead to concentration of current at the points of greatest pressure and so cause electrolytic burns. Special care should be taken in regard to the even application of the pads over bony prominences and projections. The shoulder joint is the part that requires the greatest care in this respect.

[1] A portion of these practical instructions is taken from the author's contribution to the *Instructions in the use of the Electro-medical Equipment issued by the War Office*, 1918.

When the above points have been thoroughly attended to, the current should be gently and gradually turned on by moving the revolving cross-piece in the direction of the desired polarity in the case of the shunt water resistance, or by moving the sliding contact in the case of a wire-wound resistance. In this latter case it will be found that the sliding contact will move more smoothly and readily if a slight cant up is given to its advancing edge: this procedure also causes less wear on the fine wire of the resistance. After the current has reached about one-tenth of the maximum intensity to be arrived at subsequently in the treatment, a short pause should be made. It will be noticed by reference to the galvanometer that during this interval the current strength steadily increases, reaching perhaps nearly double the strength attained at the commencement of the pause. This increase is due to the lessening of the skin resistance, the result of the damp pads and the passage of the current. The current should then be steadily increased and the process repeated at intervals until the desired strength or the toleration of the patient has been reached. When increasing the strength of the current, the expression of the patient's face and not the galvanometer should be watched. At each increase of the current the patient should be asked, 'Is that all right?', and due attention should be paid to the nature of his reply.

From time to time during the treatment the patient should be asked, 'Is it burning anywhere?' If he replies, 'It is tingling all over', the strength is sufficient for the time being. It will be noticed that immediately after the strength of the current has been increased the patient may complain of some discomfort; in less than a minute he may say that he hardly feels it: this is the time for another increase. If the patient says that the current is burning, he should be asked if the burning is confined to one spot or if the burning sensation is distributed over the whole surface beneath the pad. If he says that the sensation is general, a slight reduction of the strength is probably all that will be required. If, however, he complains that the

burning is confined to one small area or spot, the current should be steadily turned off, the bandage and pads removed, and an examination made of the affected area. It will frequently be found that the cause of the trouble is either a small pimple or a fissure of the skin, through which the current, owing to the decreased skin resistance, has concentrated and has produced the burning sensation, and would have produced an electrolytic burn in a short time if it had not been attended to. The trouble caused by the pimple or fissure may be easily overcome by applying a little collodion. The pads should again be bandaged on and the current applied as before. At the conclusion of the treatment, the duration of which should be carefully timed, the current is slowly reduced in strength, and switched off. On removal of the pads, the skin should be carefully examined for any slight burns or blisters, and if any are found they should be covered by boracic lint or other non-irritating dressing.

Any excessive redness of the skin should be treated by the application of dusting powder. The care of the skin is an important point in the application of the constant current, as its irritation or irritability may interfere with the necessary strength or frequency of the treatments.

The application of the constant current is necessarily a wet process, and mackintoshes and towels should be suitably arranged to avoid wetting the patient's clothing.

When applying the constant current longitudinally to a limb, it is usually better to apply it by means of wet towels wrapped round the limb than by the use of Schnee baths, as by the former method the diffusion of the current is more even and uniform. When using Schnee baths, owing to the conductivity of the solution in the baths being far greater than that of the patient's skin, the current flows through the fluid until it reaches its upper limit where a ring of concentration occurs.

The electrical resistance of the wet pads is relatively higher than that of the fluid in the baths and this ring of concentration does not occur when using towels. After the

treatment of a limb in the Schnee bath, a red line may be seen, produced by the concentration referred to, at the level of the limb to which the fluid in the bath reached. After treatment of a limb by the towelling wrapped round it, the limb is found to be uniformly reddened over the whole area to which the towelling was applied. It is sufficient to wrap only one or two layers of towelling round the limb, but at the lower extremity of the limb (the foot or the hand) at least four layers of towelling should be applied under the electrode.

**The Strength of the Current.** The strength of the current will vary in direct proportion to the area of the pads employed.

The following are current strengths of efficient intensity:

| *Area treated* | *Milliamperes* |
|---|---|
| Lumbar region, large pads | 80 to 100 |
| Through the hip joints | 80 ,, 100 |
| Through the knee joints | 60 ,, 100 |
| Through the ankle joints | 30 ,, 40 |
| Through the shoulder joint, antero-posteriorly | 40 ,, 60 |
| Through the elbow joint | 30 ,, 40 |
| Through the wrist joint | 20 ,, 30 |
| Four-cell baths, both arms and legs | 60 ,, 80 |
| Two-cell arm baths | 30 ,, 60 |
| Two-cell leg baths | 60 ,, 80 |
| Tic douloureux | 50 ,, 100 |
| Sciatica longitudinally from foot to sacro-iliac joint | 60 ,, 100 |

Duration of treatment should usually be from 30 to 60 minutes: the treatments should, if the condition of the skin permits, be repeated daily or on alternate days.

The pads should be of large size and should well overlap the area to be treated and the margins of the electrodes. They should be so arranged that the lines of force of the current will concentrate as far as possible on the area under treatment. Although, owing to diffusion, the current will spread beyond the limits of the pads, the path of maximum intensity will be that which lies directly between the pads. For instance, if the right knee is under treatment, the current will be more concentrated on that joint, and will

penetrate it more completely if one pad is placed on the inner side and the other on the outer side of that joint, than if the active pad is wrapped round the right knee and the indifferent pad envelops the left knee. If both knees are to be treated, two pads should be applied laterally to each knee, taking care that the two inner pads are of the same polarity. If the two pads on the inner sides of the knees were of opposite polarity, an unpleasant shock might result from the inner sides of the two knees coming in contact and so causing a short circuit.

The situation of the pads is of very great importance, and the success of the treatment largely depends on their correct arrangement so that the maximum intensity of the current is concentrated in the right direction on the area under treatment.

Whenever the constant current is applied in the region of the neck, head, or face, special care should be taken to alter the strength of the current very gradually, and the patient should always be treated in the recumbent position.

**Faradism.** The administration of the faradic current is at the present time practically confined to that form which is known as the Morton Smart or Bristow method.

The only coil suitable for this method is the one which is known as the Bristow or Smart-Bristow coil. This instrument is too well known to need detailed description, but all the coils sold under this name are not, however, identical in their action. The suitability of the coil for eliciting the graduated contraction of muscle most effectively and most painlessly depends upon the correct winding of the secondary coil. Another point to attend to when purchasing one of these instruments is to ascertain that no evidence of a contraction exists when the core is fully withdrawn; if such a contraction persists under these conditions, it is impossible to administer the Morton Smart and Bristow methods satisfactorily.

The interruptor is an important part of the apparatus. Personally I prefer a rapid interruption and in order to

obtain this I remove the adjustable weight with which the trembler is fitted.

In an earlier chapter it has been shown that the more rapid the rate of interruption, the greater is the density of the hydrogen and hydroxyl concentration, so that a lower voltage will excite an effective contraction when a more rapid interruption is applied and excitation will be proportionately less painful.

### The Method of Administration of the Faradic Current by the Smart-Bristow Method

It is first of all most important that the patient's muscles should be fully relaxed. In order to secure this relaxation, the patient should be recumbent on a couch with the knee semi-flexed by a pillow placed under the popliteal space when treating the muscles of the knee joint; or should be comfortably seated on a chair with the arm supported on a pillow when the arm or shoulder muscles are under treatment.

At the first treatment it is often difficult to secure adequate relaxation owing to the patient instinctively rendering himself rigid in opposition to the unusual contraction of his muscles. The first treatment is often not so effective as it might be owing to this resistance on the part of the patient: at subsequent treatments, however, the patient usually submits in a passive manner to the electrical excitation. Much may be done to overcome the passive resistance of the patient by engaging him in conversation.

Next in importance to the comfortable arrangement of the patient is the comfort of the operator. He should be seated with the coil placed on a table at his right hand, his fore-arm should rest on the table holding the movable core lightly in his right hand and should sheath and unsheath it by a regular movement of his wrist.

The process of moving the core consists of four parts:

1. A slow even sheathing of the core.
2. A definite pause after the core has been sheathed.

3. A gradual and even unsheathing of the core.
4. A definite pause of rest. Then the process is repeated.

At the same time the operator holds the small active electrode, covered by a well-damped sponge or piece of Turkish towelling, between the thumb and forefinger of his left hand, and applies it to the muscle under treatment, simultaneously gripping the muscle and noting the type of contraction elicited.

The large indifferent electrode is bandaged on to a convenient spot or secured in position by the weight of the limb or body resting upon it. Preferably it is placed in the neighbourhood of the tendon of the muscle under treatment: it should not be placed, if it can be avoided, over a group of muscles of opposing action to the muscle under treatment.

The theory of the action of this treatment, given in detail in an earlier chapter, should not be lost sight of, namely, that its action is to produce tension or a pull on the tendon of the muscle treated, and so restore the natural currents which normally maintain the tone of the muscle, when from injury to the joint or muscle, it has for the time lost these currents and the resulting tone from reflex action. This tension or pull on the tendon will not result from one or two irregular contractions of the muscles elicited in a perfunctory manner, for the muscle tone can only be efficiently restored by carrying out the correct technique laid down by Morton Smart and Rowley Bristow. No other form of electrical treatment is so frequently misapplied and in few forms of treatment is a correct technique of greater importance than in this method of the electrical excitation of muscles deficient in their natural tone.

The duration of each treatment must depend upon the condition of the muscles and must be judged by the type of response elicited in them. If, during treatment, the contraction becomes of a weakened, irregular, or flickering type, the electrical excitation should be immediately stopped.

Improvement will often be noticed after the first treatment, and in most cases after six to twelve treatments the tone of the muscle is sufficiently restored to enable the patient to complete his cure by suitable exercise.

The extensor muscles of the thigh are the muscles that most frequently call for this treatment. After an injury to the knee joint, the tone of these muscles has been reflexly lost, and the knee joint, deprived of the natural support of these muscles, is found to be weak, painful, and liable to twists or strains. The special technique in these cases is to bandage the indifferent electrode over the upper third of the anterior surface of the leg, and apply the active electrode in turn over the vastus internus an inch or two above and to the inner side of the patella, to the quadriceps extensor at the junction of the upper and middle third of the thigh on its anterior surface, and over the tensor fasciae femoris at the upper third of the outer side of the thigh, so exercising tension on the important ilio-tibial band.

The other applications of this treatment are too numerous to mention in detail. Especially good results are obtained in the treatment by this method of the adductor muscles after injury in Rider's Strain, and, as Dr. Murray Levick has pointed out, in the treatment of a flat transverse arch of the foot, by a small pad placed over the dorsal interossei at the base of the toes. In this latter case, an active electrode may be applied to each foot, or, if only one foot is affected, the indifferent electrode may be bandaged over the peronei.

**The Sinusoidal and Watteville Currents.** These currents depend for their therapeutic action upon the wave of hydrogen concentration at make and upon the wave of hydroxyl concentration at break that extend from pole to pole throughout the tissues at the onset and interruption of each phase of the current. In this way a wave of stimulation occurs deeply through the tissues at each phase of the current's variation.

In actual practice I have found the Watteville by far

the more effective of these two currents. This is probably due to the super-position of the galvanic upon the sinusoidal or faradic current. Sometimes the Watteville current is spoken of as the combination of the galvanic current with the faradic and sometimes with the sinusoidal current.

For therapeutic purposes the combination with the sinusoidal is usually the more effective, and it is that combination which is implied in the description of the Watteville current given below. As a general rule the galvanic current should be so arranged that it is in tension with the pole to which the active electrode is attached.

It is true that with the faradic current a wave of stimulation by ionic concentration extends from pole to pole at the make and break of the current, but with the small active electrode employed in that case the stimulation is a very rapidly decreasing quantity from the active to the indifferent electrode. With the larger electrodes employed with the Watteville current, the stimulation is more widely and uniformly distributed throughout the tissues. The rapid make and break of the faradic current sets up a shorter duration (1/1,000 sec.) and a greater density of the ionic concentration: its voltage is also far higher, and it therefore excites a far more vigorous contraction than can be elicited from the sinusoidal current. The sinusoidal current (with a periodicity of about 50 a sec.) is more gradual and prolonged in its onset and decline, its density and voltage are much lower and consequently it produces a more prolonged action. By the use of the two forms of current yielded by the author's rotary surger (Figs. 8 and 9) two distinct types of stimulation are obtainable, the one of lower voltage, exciting only an almost imperceptible tremulation of the muscles, producing its effect at each half-revolution of the surger, and reaching its maximum intensity alternately at either pole of the apparatus. This form is indicated when it is desired to produce deep ionic stimulation of the tissues without the excitation of muscular contraction. For instance, in

the treatment of oedematous legs no other method yields such good results, and in the treatment of chilblains and similar conditions it is the method of choice.

In the other method of using this apparatus, one of the stationary rods is shorted back to the source of supply (as explained on p. 90). The shunt path for the current is thus cut out and the voltage obtained is consequently higher; more vigorous muscular contractions are thus excited than with the other method. In this form of using the surger, owing to cutting one of the revolving rods out of action, the stimulation only occurs at each complete revolution instead of each half-revolution. Owing to the comparatively lower voltage and density of the current obtainable from this method compared with that yielded by a faradic coil, the muscular contractions excited by its application are far less vigorous. It, however, affords a useful means of treatment intermediate between that obtained by the use of the surger in its other form and that obtained by the employment of the faradic coil. The indications for its use are when mild and not vigorous muscular contractions are required. It is especially indicated for the restoration of muscle tone in the later stages of the treatment of sciatica. It will often be found that, when the acute symptoms of sciatica have passed off, pain or aching is still excited by standing or walking. Such pain or aching is often the result of the deficient tone in the muscles of the leg, throwing undue and unaccustomed strain on the ligaments of the joints and other parts. The contractions elicited by the faradic coil are at this stage too vigorous in character and in such cases I have found the surged Watteville current far more beneficial. This treatment is also useful for the restoration of tone to flabby abdominal muscles.

For the administration of the Watteville and sinusoidal currents the same pads, electrodes, and rheophores may be employed as for the constant current: hand and foot baths are a convenient means of their employment.

With these currents, owing to the frequent reversal of

the polarity, the danger of electrolytic burns is absent. Interrupted currents of this character must never be administered over the cardiac area.

The choice of a diathermy machine at present seems to rest between a triode valve apparatus and an apparatus fitted with a multiple, tungsten, air-cooled spark gap, the regulation of the machine being controlled by loose-coupling coils.

### The Administration of High-Frequency Currents of Tension and High-Frequency Currents of Quantity (Diathermy)

The modern type of diathermy apparatus is one of very high frequency, up to 2,000,000 oscillations or more with the valve type.

Certain conditions such as hyperpyesis are more benefited by a lower frequency, for with the lower frequency the high-frequency effects other than those of heat are more pronounced owing to the greater range of the oscillations. For the production of such currents the old form of apparatus, in which the input is stepped up by an induction coil, appears to be the most effective type.

There are many excellent kinds of diathermy machines of the spark type manufactured in this country, and it would be difficult and invidious to select any one kind as the best. It is probable, however, that the diathermy machine of the future will be of the triode valve type. So far as I am aware at the time of writing, no machines of the valve type are manufactured in this country. Three types of diathermy apparatus yielding continuous or undamped waves of oscillations by means of the triode valve are procurable from M. Chenaille, 163, Rue de Sèvres, Paris. The following are the prices of the three types, packing, carriage, and duty paid, delivered in London.

1. The 'grand modèle', 300 watts, 4 to 5 amperes, one lamp, price £60.

2. 'Le modèle à grande puissance', 500 watts, 6 to 7 amperes, one lamp, £80.

Fig. 33. The Chenaille Triode Valve Apparatus. 'Le modèle à grande puissance.'

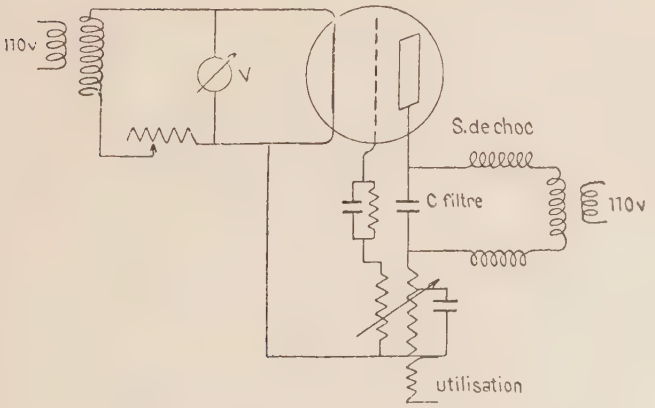


Fig. 34. Schematic diagram of the Chenaille Triode Valve Diathermy Apparatus.

3. 'Le modèle à très grande puissance', 1,000 watts, 10 to 12 amperes. With two lamps. Price £150.

The 1,000 watt model is intended only for hospital use, where it is wished to treat several patients simultaneously from one machine.

The most generally useful model and that in most demand is the 500 watt type.

The triode lamps are guaranteed for 1,000 working hours, and the rest of the apparatus for two years.

The chief advantages of the triode valve machines are their absolute silence, the absence of any fumes or smell, the complete freedom from any faradic sensation, perfect safety, their large output, and the fact that they need no cleaning or adjustments. The chief disadvantage is the liability of the valve to break and the need for its replacement, at an approximate cost of £7, after about 1,000 working hours. Against the cost of a new valve the saving of current consumption may be regarded as a partial offset.

In regard to the spark gap machines, the multiple tungsten spark gap, as generally used in America, obviates the need of coal gas for cooling purposes. This is a great advantage, as coal gas is not always available, and,when it is, there is often a difficulty in securing a gas-tight joint in the spark gap.

The regulation of the output by loose-coupling in place of a sliding contact on the solenoid is another advantage as, after some use, the sliding arm fails to make good contact with the result that sparking occurs and trouble soon ensues in the working of the apparatus.

In the selection of a portable apparatus, the purchaser must bear in mind that these are of two types, one to work off a lighting circuit, in which case the intake must not exceed 5 amperes: the other to work from a supply wired to carry sufficient amperage for heating purposes.

In the former case, the instrument will fail to give the 1·5 to 2 amperes output required for the treatment of

pneumonia, for the treatment of which condition these machines are especially required.

In the latter case, the instrument cannot be used in an emergency from the supply of a house that is only wired for lighting purposes.

In this respect the purchaser of a portable set is consequently in rather a dilemma, the ultimate solution of which may be found in a suitably designed triode valve apparatus, for with such a type the loss in functioning is far less than with the spark gap machines.

The electrodes and rheophores described for the application of the constant current are equally suitable for the administration of diathermy. The boomerang-shaped electrode is especially recommended for the treatment of the knee: for in the treatment of this joint the limb is placed in a position of semi-flexion by the aid of a pillow under the popliteal space, as such a position aids relaxation and so conduces to the comfort of the patient. When the ordinary rectangular electrodes are applied in this position, their lower and anterior extremities approximate in the region of the patellar tendon, and as the diathermy current takes the shortest path between electrodes, this region becomes unduly heated and sufficient current cannot be passed through the joint. The boomerang electrodes lie evenly along the sides of the joint and this concentration does not occur.

In the arrangement of the electrodes perfect co-aptation of surface and security of fixation are of the greatest importance. If the electrodes are unevenly applied, concentration of current may occur at one point and a severe burn may very quickly result. If an electrode becomes detached either owing to faulty bandaging, or from the patient's jumping away from an electrode upon which he has been resting, there is always one small point at which contact is the last to be completely broken; the current concentrates at this small point of contact or may leap from the detached electrode in the form of a very hot spark, and immediately causes a burn. For instance, if a 20 × 10 cm.

electrode has been applied under a patient resting on his back and has been secured in position merely by his weight resting upon it, feeling the current too hot, he may jump away from the electrode, the full strength of the current will then concentrate at the corner of the electrode last in contact or jump from it in the form of a hot spark, and on examining the back of the patient, a small indurated white area will be found which will be a source of trouble for weeks to come.

Whenever contact is secured by any part of the patient's body resting upon an electrode, the patient should always be warned against jumping away from the electrode. The danger of the last point of contact should be pointed out to him, and he should be told to complain at once when the current becomes uncomfortably hot, in order that its strength may be reduced in time. It is often very convenient to employ this method of application by the patient's weight resting on the electrode or pad, as it is no easy or light task to secure the electrodes back and front by several turns of roller bandage round the protuberant abdomen of an inactive, obese, and heavy patient. It is safest, however, to take one such turn, which, though insufficient to secure even apposition, this being obtained by the patient's weight, is sufficient to prevent a complete breach of contact if the patient should jump away from the pad. I have dealt with this point in detail, as it is one of the most frequent causes of diathermic burn.

A diathermic burn differs from a galvanic or constant current burn in several particulars. It occurs more suddenly. It is less painful. It is usually deeper and heals more slowly. It may be much more severe in character. It is a true heat burn, and not an electrolytic or chemical burn.

Great divergence of opinion exists among electrotherapists in regard to the question whether the electrodes should be applied to the skin without the interposition of any pad, that is to say, perfectly dry or moistened only

by the application of soap lather: or whether a wet pad should be interposed between the surface of the skin and the electrode. In America and France the bare electrode is mainly used; in this country it is usual to apply the current through the medium of wet pads. Bordier, than whom no greater authority on diathermy exists, is a strong advocate of the bare electrode, and in a recent paper[1] ('Anomalies observées dans les effets calorifiques de la diathermie appliquée au moyen d'électrodes spongieuses. Graves inconvénients de ces électrodes en thérapeutique'), as the result of many experiments, comes to the conclusion that 'The diathermic current of D'Arsonval ought to be applied by means of metallic and not by wet electrodes.'

I have frequently tried both methods, both on patients and on myself, and the conclusion that I have arrived at is that in certain cases, such as where large fleshy surfaces free from bony projections are beneath the electrodes—for instance, when applying the current transversely through the buttocks—it is often convenient to employ bare electrodes to which a liberal application of soap lather has been applied: the main advantage being that in this case no precautions have to be taken against wetting the patient's clothing. In the majority of cases, however, the interposition of pads, well moistened with a solution of sodium chloride, the exact strength of which I do not worry about, is much to be preferred.

I find that even during long treatments the pad itself does not heat unduly, rarely reaching 99° F., and that it certainly does not heat sufficiently to cause a burn from the conduction of its intrinsic heat.

The main advantages of the pads are that the current can be more evenly applied over bony surfaces and that the underlying skin is more uniformly heated. With dry electrodes so applied as to transmit the current transversely through a limb, at the end of the treatment the skin at the margin of the electrodes exhibits a red line

[1] *Archives d'Électricité Médicale*, February 1928.

due to the concentration of the current along the margins of the electrodes. (This marginal action must not be confounded with the 'edge' action that occurs at the lower edge of the upper electrode and the upper edge of the lower electrode when the so-called 'cuff' electrodes are applied one above the other on a limb.) When wet pads have been applied, the skin after a prolonged treatment is found to be uniformly reddened and these marginal lines of redness cannot be detected.

A greater current can be tolerated, and a higher amperage can be obtained with wet pads than with dry electrodes. For instance, in the treatment of rheumatic shoulder, one patient could hardly tolerate 700 ma. with dry electrodes. I switched off the current, and interposed wet pads without any readjustment of the instrument: the amperemeter then recorded 900 ma., a strength which the patient tolerated without the slightest discomfort. In this case there was a faint tingling experienced when the dry pads were employed, and the patient remarked, 'Oh! This feels more like a battery.' If dry electrodes are used, the current should be turned on more gradually to allow the moisture of the heated skin time to perfect the contact. My experience is that patients almost always prefer the wet pads, and I have been compelled on several occasions, when using dry electrodes, to stop the treatment and interpose wet pads.

The question is one which may be best settled by personal experiment. Let the electrotherapist, before he arrives at a definite conclusion, try both methods on himself. Let him place two dry electrodes, one on either side of one knee, and two electrodes of similar area and shape over wet pads in a corresponding position on the other knee, and connect the two inner rheophores to one terminal of the apparatus, and the two outer rheophores to the other terminal. Let him then turn on the current to toleration strength and note the sensation on the two knees. Let him next, with a similar adjustment of the instrument, treat one knee at a time, and note by reference

to the amperemeter whether the dry or wet electrodes pass more current.

Very often it is desirable to follow the application of diathermy by the administration of the constant current: thus securing the more immediate effects of the former and the more lasting effects of the latter. In this case the employment of wet pads for the diathermy treatment avoids the necessity for readjustment of the patient when the constant current is applied.

The diathermic current, as has already been explained, enters the body partly by conduction, and partly as the result of a more or less leaky condenser action. When applying diathermy by means of the condenser couch, it is evident that the condenser effect must be at its maximum; when using dry electrodes, the leaky condenser action is in play; and, when using wet pads, the passage of the current by conduction must be relatively far greater. Provided that the amperage obtained is the same, it is immaterial whether the current enters the body by a pure condenser, leaky condenser action, or simple conduction.

A very unfortunate occurrence that was reported to me a few years ago illustrates very strikingly how much more readily the diathermic current, under certain conditions, passes by conduction than by condenser action.

A baby was being operated on by diathermy for a naevus; the infant was placed on a flexible condenser pad, composed of a sheet of copper gauze over which an overlapping sheet of asbestos was laid. Whilst this sheet was dry, it served as an efficient and safe indifferent electrode of the condenser type. Unfortunately, during the proceedings, the baby passed urine, and, by so wetting the asbestos sheet, afforded a path of conduction along which the current concentrated causing a very severe burn on the baby's buttocks.

For the use of beginners I append some elementary instructions that I drew up some years ago. They especially apply to hospital practice. The pads should correspond

in surface area to the electrodes under which they are placed. As the amount of current which can be tolerated varies directly as the square of the surface area of the pad or electrode, it is essential, in order to standardize dosage, that the areas of the pads or electrodes should also be standardized.

The following are the sizes of the electrodes usually employed and the strength of the current which with due precautions may be safely employed with them.

| *Size of electrodes in Inches* | *Current strength in Milliamperes* |
|---|---|
| Rectangular electrodes | |
| 8 × 4 | 1,500 to 2,000 |
| 4 × 2 | 900 to 1,000 |
| $2\frac{3}{4} \times 1\frac{1}{2}$ | 500 |
| Circular electrodes | |
| $3\frac{1}{2}$ diameter | 900 to 1,000 |
| $1\frac{1}{2}$ diameter | 300 |
| 1 diameter | 200 |

The dosage stated above only applies when the current is transmitted transversely through the body or across a limb. When the current is applied longitudinally along a limb, as for instance from foot to hip, or from hand to hand, the dosage is limited by the narrowness of the ankle in the one case and the wrist in the other: in these narrow parts the current and the heat are most concentrated, and the area of the pad has no influence on the dosage.

The dosage should not exceed 500 ma. through the wrists and 700 ma. through the ankles.

The diathermic current takes the shortest path from one electrode to the other, with little or no diffusion. Grasping an electrode in each hand and fully flexing the wrist, the heat will be felt chiefly along the flexor surface of the forearm and wrist: by extending the wrist fully the extensor surface becomes the hotter. The pads must, therefore, be so applied that the area to be treated lies in the direct path between the two electrodes. When applying the treatment longitudinally, the direction of

the heat may be affected by the position of the limb: by flexing the knee, for instance, the heat may be concentrated in the popliteal space. The direction which the current will take should always be considered when applying the pads. When the current is applied transversely, the skin, having the greatest resistance of any tissue through which the current passes, will heat the most. The sensation of heat experienced by the patient affords a guide to the strength of current to be applied. The current should at once be stopped, if the patient says that it is too hot or that it is burning him, especially if he complains that it is too hot at one spot rather than over the whole area of the pad. The skin will be found to become hottest where there are subcutaneous bony surfaces, and especial care is required in the treatment of these areas. If the pads are not placed exactly opposite one another, but one a little higher than the other on the limb, the heat will concentrate on the lower edge of the upper pad and the upper edge of the lower pad. This is a faulty method of application, as the current, concentrating on a linear patch on the skin, prevents sufficient heat being applied to the deeper tissues. Pads encircling a limb, one applied above the other, excite an edge action: in most cases this is a bad method of application, as the current is concentrated on the skin and very little, if any, reaches the deeper tissues.

The success of diathermy depends upon its application in the right direction and over the right area. In transverse treatments the deeper structures may be more intensively heated by the employment of the 'cross-fire' method, as, for instance, in treating the knee joint, the pads may at first be applied laterally and then antero-posteriorly.

In treating areas where the appreciation of heat has been impaired or lost, namely, in certain cases of paraplegia, intermittent claudication, &c., the very greatest care must be exercised, only very small currents must be used, and the pads must be removed every few minutes

in order to inspect the condition of the skin. In applying the current longitudinally, special care must also be exercised as the deeper structures cannot appreciate changes in temperature.

Moreover, in the case of longitudinal treatments of a limb, the current is longitudinally heating a column of blood throughout the length of the limb, instead of there being, as is the case with transverse treatments, a stream of blood continually flowing transversely to the part treated and so carrying away a considerable proportion of the heat energy to other parts of the body. The heat from a limb, however, radiates outwards, and so may be appreciated over the narrowest areas, where the heating effect is greatest—ankles, wrists, &c., and this may serve as some guide to the dosage. The real danger signal, however, in longitudinal treatment is not the sensation of heat, but the acute pain which occurs in the limb when the heating effects are too great: the current should be turned off at once when such a pain is complained of. Any aching in the limb is also an indication for the current to be reduced in strength or switched off.

In the treatment of certain areas the electrodes should be held in position by the operator. It is, for instance, difficult to secure the electrodes firmly in position by bandages, without throttling the patient, when applying the current laterally through the neck. In this case the electrodes may be effectively applied by the operator, standing behind the patient, holding the electrodes on the sides of the neck, and switching the current on and off by means of a conveniently placed foot switch. Under such conditions, the current must either be adjusted before switching on, or its strength must be adjusted by an assistant. An ingenious method of overcoming this difficulty has been suggested by Dr. Curtis Webb. A towel is folded longitudinally into the form of a neck-cloth, its centre is placed over the back of the patient's neck, its sides placed over the electrodes, and its ends brought forward and held during the treatment by the

patient. This method secures a very even application of the electrodes and leaves the operator free to control the current.

When it is desired to treat a small area intensively, such as the painful area over the external condyle of the humerus in the case of tennis elbow, the active electrode should be held in position and removed every minute or less to inspect the condition of the skin. In this way it is possible to treat small areas far more intensively and safely than by securing the electrode in position with a bandage that does not admit of ready removal.

There is a method, of American origin, that is very useful in administering diathermy to the ear. A cylindrical hand electrode is held between the thumb, middle, ring and little finger of each hand, and the forefinger of each hand is inserted just within each external auditory meatus. By the heating of the finger the right amount of current may be judged. This method may be applied by either the operator or the patient holding the hand electrodes in the manner described. A rather better line of force, when treating the middle ear, is secured by the operator placing his first two fingers over the mastoid process and the first three fingers of the other hand over the patient's face on the opposite side, midway between the eye and the ear, and holding the hand electrodes between the thumb and the remaining fingers of each hand.

When treating the base of the neck over the trapezius muscle, or over the clavicle or shoulder, the best line of force can be secured by seating the patient on a condenser couch and placing the active electrode over the affected area.

The condenser couch may be constructed by a sheet of metal overlaid and overlapped by a $\frac{3}{16}$ inch sheet of ebonite, or the 'diélectrique souple' of Bordier may be employed.

In view of the accident to the infant recorded above, a flexible non-waterproof condenser sheet should not be used for children, or where wet pads are applied.

*A patient, whilst being treated by diathermy, should never be left unattended.*

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